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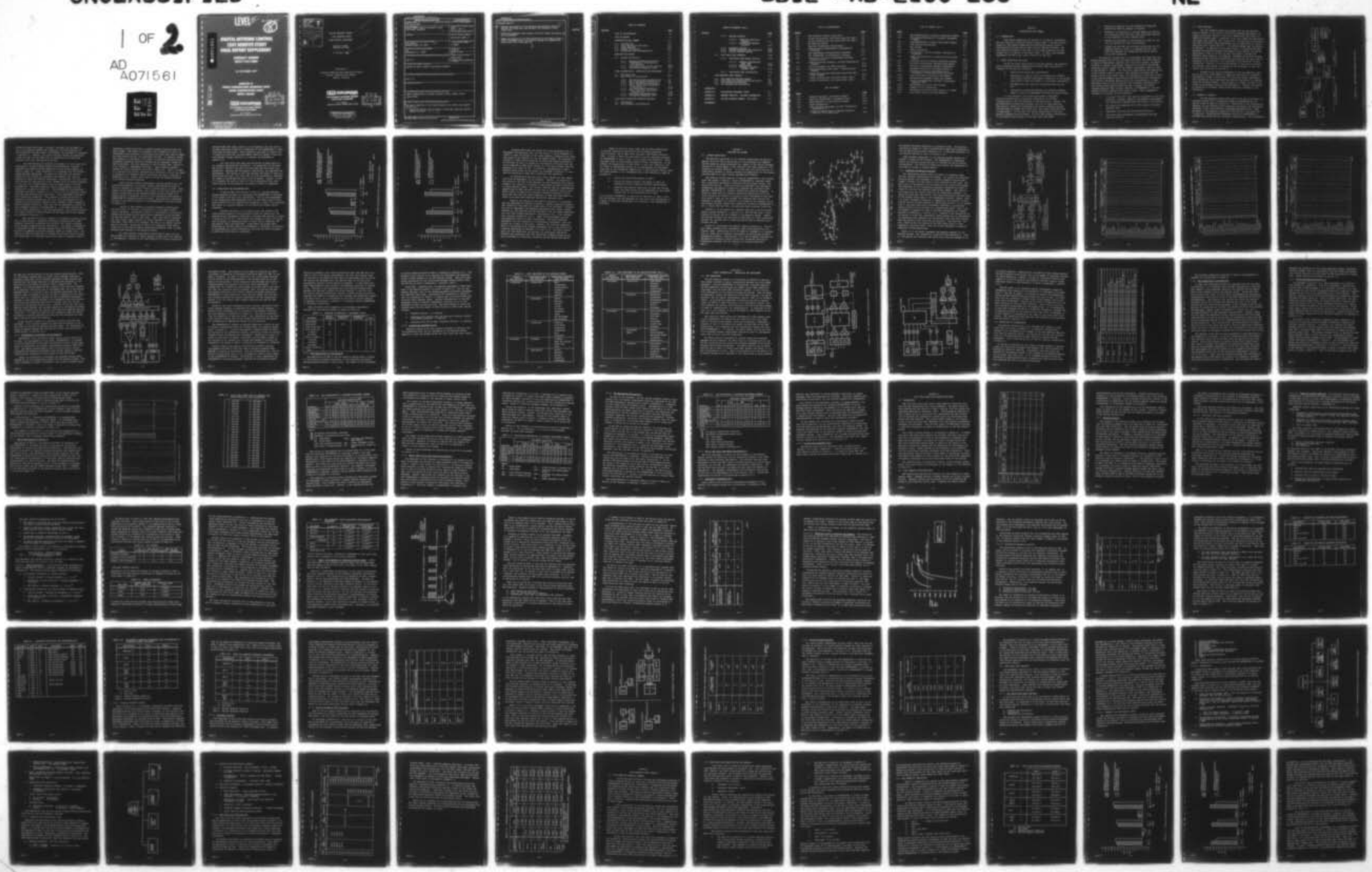

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The overall objectives of this Digital Network Control (DNC) costs benefits analysis are:

a. Specify and quantify the cost benefits of those DNC operational benefits capable of analysis. (over)

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b. Determine the optimality of the DNC design and application resulting from the first eight tasks when examined in the framework of total network costs.

c. Examine the dependence of DNC hardware on ATEC for control and quantify any cost relationships.

d. Compare and contrast the five DNC alternatives and the baseline system in order to recommend the most cost-effective approach for augmenting DCS system control with a DNC capability.

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This report summarizes the results of a study to investigate the cost benefits of Digital Network Control (DNC). The work was performed for The Defense Communications Engineering Center during a three-and-a-half month period under contract DCA100-76-C-0064. The cost benefits analysis is the last of nine tasks comprising the DNC program and is an add-on to the basic study. As such, this document supplements the DNC final report issued on 27 May 1977.

1.2 STUDY OBJECTIVES AND SCOPE

During the first eight tasks of the DNC program, the projected digital European Defense Communications System (DCS) was used as a framework to achieve the following:

a. Identify and analyze DNC requirements

b. Demonstrate by analysis that an automated and remotely controllable channel reassignment capability is the optimal application of DNC with respect to functional requirements

c. Recommend the time frame for introducing DNC into the DCS

d. Conceptually design DNC hardware and software elements based on a set of recommended functions and applications.

It was determined that system performance enhancement derived from DNC makes it extremely advantageous to consider including some or all DNC functions in the future DCS. However, the decision-making process must consider the cost of these benefits. Specifically, operational performance and control benefits derived from DNC must be traded off against life cycle costs associated with its deployment. To this end, the overall objectives of this cost benefits analysis are as follows. For five DNC hardware alternatives to the baseline DCS planned for the post 1984 time frame:

a. Specify and quantify the cost benefits of those DNC operational benefits capable of analysis

b. Determine the optimality of the DNC design and application resulting from the first eight tasks when examined in the framework of total network costs

c. Examine the dependence of DNC hardware on ATEC for control and quantify any cost relationships

d. Compare and contrast the five DNC alternatives and the baseline system in order to recommend the most cost-effective approach for augmenting DCS system control with a DNC capability.

The specific alternatives to be considered are based upon the planned European DCS for the post-1984 time frame, the DNC-A function (a channel reassignment capability for T1 digital groups), the DNC-B function (a channel reassignment capability for both T1 and TRI-TAC formatted digital groups) and the channel reassignment function (CRF) of the AN/TSQ-111 (CNCE). The functions, applications and engineering of DNC elements used as inputs to this analysis are based upon the results of the first eight tasks. The application of the CRF is based on the CNCE development specification and DCEC-furnished information. The analysis considered application of the alternatives to a representative subset of the European DCS and reflected consideration of the Frankfurt-Koenigstuhl-Vachingen (FKV) Program, the Digital European Backbone (DEB) Program, AUTODIN I, AUTOSEVOCOM II, and the Defense Satellite Communication System (DSCS). Major assumptions inputted to the study are the following:

a. A 10-year life cycle cost analysis performed for the years 1984-1993. However, research, development, procurement, and installation expenditures occur prior to this period.

b. All costs are discounted to FY 1977 using a 10 percent discount rate.

c. Escalation rates are per DCA Circular 600-60-1.

d. Life cycle cost techniques are consistent with DCA Circular 600-60-1.

1.3 STUDY APPROACH

The cost benefits study was divided into the two subtasks shown in Figure 1-1 as a means of achieving program objectives in an orderly and logical fashion. The first subtask uses the results of tasks one through eight, in addition to GFI, as a basis for specifying life cycle cost analysis (LCC) constraints, for modifying GTE Sylvania's LCC model to reflect these constraints, and to ensure costing consistency with DCA Circular 600-60-1. The second subtask uses the results of subtask 1, in addition to the other inputs, to determine CRF/CNCE hardware and software elements applicable to DNC; specify the optimal application of DNC to the DCS for each alternative; analyze and quantify, where possible, DCS manpower, equipment and circuit mileage savings derived from each alternative; and calculate the total cost of ownership to the Government (LCC adjusted by cost benefits) of each alternative. Implicit in the second subtask is that each alternative is optimized with respect to engineering and deployment so that the results are objective and conclusive.

Because of the obvious dependence of the cost benefits analysis on the first eight tasks for inputs and applications, extensive referencing is made to the 27 May 1977 DNC final report (Reference 1). This referencing also eliminates the repeated requirement to redefine terms and rederive results. Unfortunately, it places a burden on the reader to be somewhat familiar with Reference 1. However, the report is organized to minimize, except where absolutely necessary, this familiarity.

1.4 SUMMARY OF RESULTS

The DCS baseline against which each of the DNC alternatives is compared consists of 90 transmission nodes interconnected by 100 digital links as shown in Figure 2-1. Twenty-nine of the stations are unmanned, 20 are staffed by both technical controllers and maintenance personnel, and 41 are staffed by maintenance personnel only. ATEC equipment in the baseline consists of three sectors, nine nodes and 59 stations. The switching complement, as part of AUTOSEVOCOM II, includes four AN/TTC-39s and 26 digital concentrators. The transmission

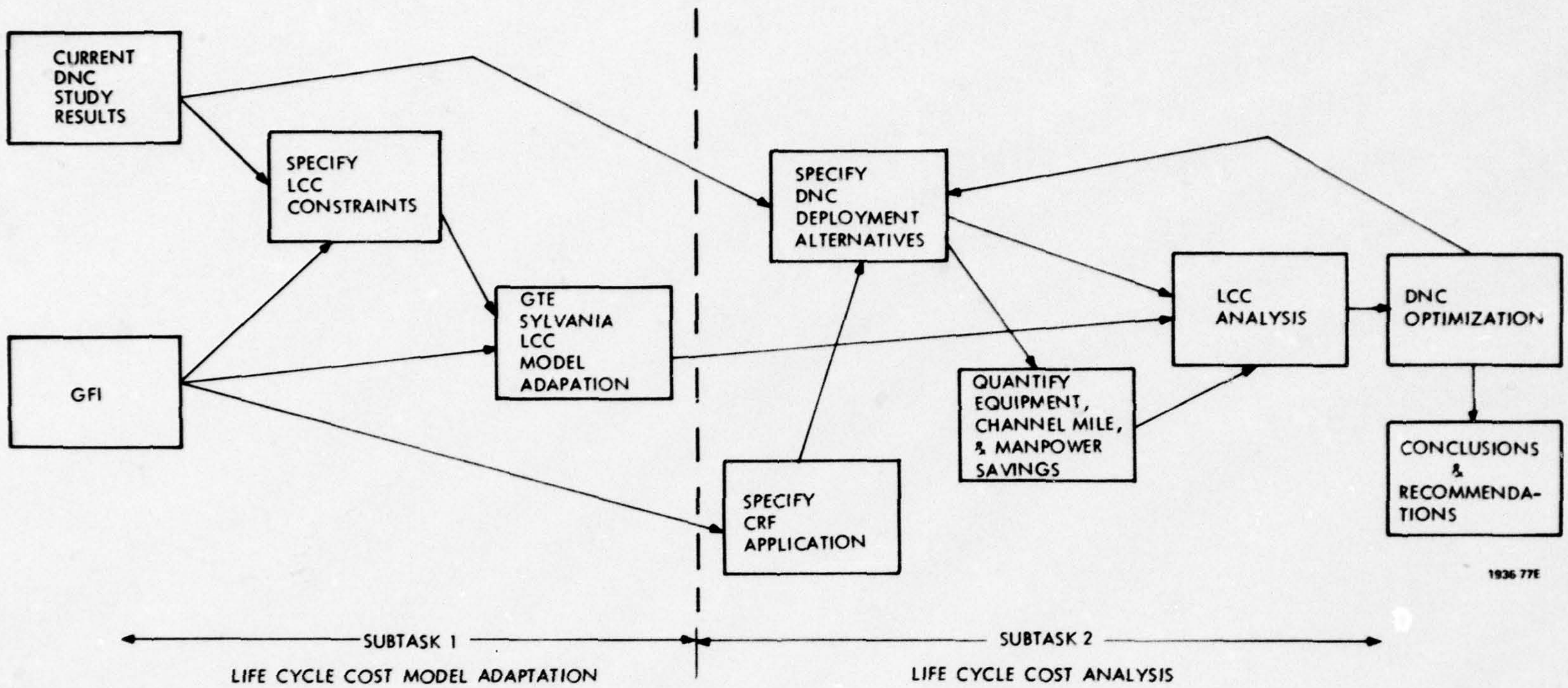

Figure 1-1. Cost Benefits Analysis Study Plan

network includes DEB stages 2 through 4 and DSCS; FKV and DEB-1 are not in the baseline because the location of the bulk encryptor in these networks preclude channel reassignment, as discussed in Reference 1, section 4.7. However, the results obtained herein are applicable to FKV and DEB-1 at the added cost of replacing the CY-104s with separate first level multiplexers and KGs.

Six alternatives are analyzed with respect to life cycle costs. Alternative 1 is the baseline system and Alternatives 2 through 6 represent the baseline system augmented by various DNC elements, as shown in Table 3-1. Each alternative is considered with and without a supporting ATEC deployment. It should be noted that the baseline system does not include all equipment and manpower that would be deployed at those DCS stations considered. Accordingly, the life cycle cost derived for the baseline is not intended to be an absolute measure of its cost, but a gauge against which to compare each of the DNC alternatives. The basic technical control configuration for each alternative is shown in Figure 2-2. The AUTOSEVOCOM II/transmission interface is shown in Figures 2-3, 3-1 and 3-2 for the baseline, DNC-A/DNC-B and CRF alternatives respectively. DNC-A Deployment provides a full flexibility capability. This permits a network controller to establish a channel between any two first level multiplexers in the network during unstressed conditions and a somewhat lesser capability during stressed conditions. DNC-B and the CRF deployments provide for the automated interface of AUTOSEVOCOM II. A two-phase process was used to ensure optimality of the DNC deployments. The process resulted in a design change to DNC-B hardware and DNC application rule changes as discussed in section 5.4.

DNC alternatives require changes to the baseline manning levels due to three factors: technical controller automation due to ATEC, technical controller automation due to DNC-A, and overall equipment level changes accompanying each alternative. The impact of automation is estimated through a queueing analysis where the technical control facility is modeled by an M/M/k queueing system in steady state. The effects of DNC-A and ATEC are to increase the service rates of technical controllers or to decrease the arrival rates of technical control

operations, thereby providing a tradeoff between manning levels and queue length. The impact of equipment level changes is to alter the maintenance level workload in accordance with total mean-time-to-repair and mean-travel-time for the equipments involved. In general, automation results in a decrease in the number of technical controllers and maintenance personnel required; whereas the net equipment change for each alternative, with the exception of DNC-B without ATEC, results in a net increase in maintenance personnel. Total baseline manpower changes for each alternative are given in Table 4-11. Case 1 in Table 4-11 indicates the results representing an optimistic view of the impact of automation on technical control functions, and Case 2 indicates a pessimistic view. Cases 1 and 2 serve to bound the manning benefits to be derived through automation.

DNC-A through channel reassignment requires breakout only for terminating channels at a station, thereby eliminating the need to drop all channels in a group in order to access part of a group. With respect to the baseline system, this results in the first level multiplexer savings shown in the rechannelization column of Table 4-12. Another source of equipment savings is the transmission efficiency of AUTOSEVOCOM II channels provided by DNC-B. The quantity of equipment savings in this case are shown in the AUTOSEVOCOM II interface column of Table 4-12.

Control of DNC hardware is achieved through a hierarchical structure which is physically integrated into the planned system control subsystem. Operational control of the hardware is distributed between the processor within each station complement of DNC hardware, and network control (NCS in ATEC case). Thus, when ATEC is deployed, the only control costs incurred are those required to interface DNC with ATEC. When ATEC is not deployed, the cost of an overall network must be incurred. Column one of Table 4-13 summarizes these costs. Column two is the DCEC estimated uninstalled equipment costs for ATEC hardware when deployed in the baseline system.

All three channel reassignment devices DNC-A, DNC-B and the CRF provide the potential to reduce channel mileage over that required in the baseline. Because of the unavailability of circuit routing for

the post-1984 time frame, which is to be expected, only the circuit mileage reductions relating to automation of the AUTOSEVOCOM II interface could be determined. These reductions are shown in Table 4-14. It should be noted that the DNC-A/DNC-B reduction equals a total network channel mileage reduction of 2 percent, as discussed in section 5.2.

The life cycle cost model was structured to adapt easily to all network configurations considered. In preparation of the model, DCA Circular 600-60-1 was used in structuring the three major cost categories: Research and Development, Acquisition, and Operating and Maintenance. The results of the cost analysis are shown in Table 5-1, which gives the total life cycle cost for each alternative, including the impact of those benefits which could be costed. Figures 1-2 and 1-3 translate the costs in Table 5-1 into differential life cycle costs relative to the baseline, and provide a basis of comparison.

1.5 CONCLUSIONS AND RECOMMENDATIONS

As may be seen from Figures 1-2 and 1-3, the DCS baseline system augmented by DNC-B for automating the AUTOSEVOCOM II interface is the lowest life cycle cost alternative. This is true independent of an accompanying ATEC deployment and over the widest range of manpower reductions to be expected from automation. Thus, it is concluded that DNC-B is a desired addition to the future DCS system control subsystem.

Another conclusion of the study is that the relative cost effectiveness ranking of the alternatives does not change over the expected range of manpower reductions or between ATEC options, as shown in Figures 1-2 and 1-3. The ranking with respect to total life cycle cost is always, in decreasing order of costs, DNC-B, Baseline, CRF, DNC-A/DNC-B, DNC-A and DNC-A/CRF. Since DNC-B has already been determined as the most effective AUTOSEVOCOM II interface, the CRF can be eliminated as a viable alternative, and only the joint deployment of DNC-A and DNC-B must be considered.

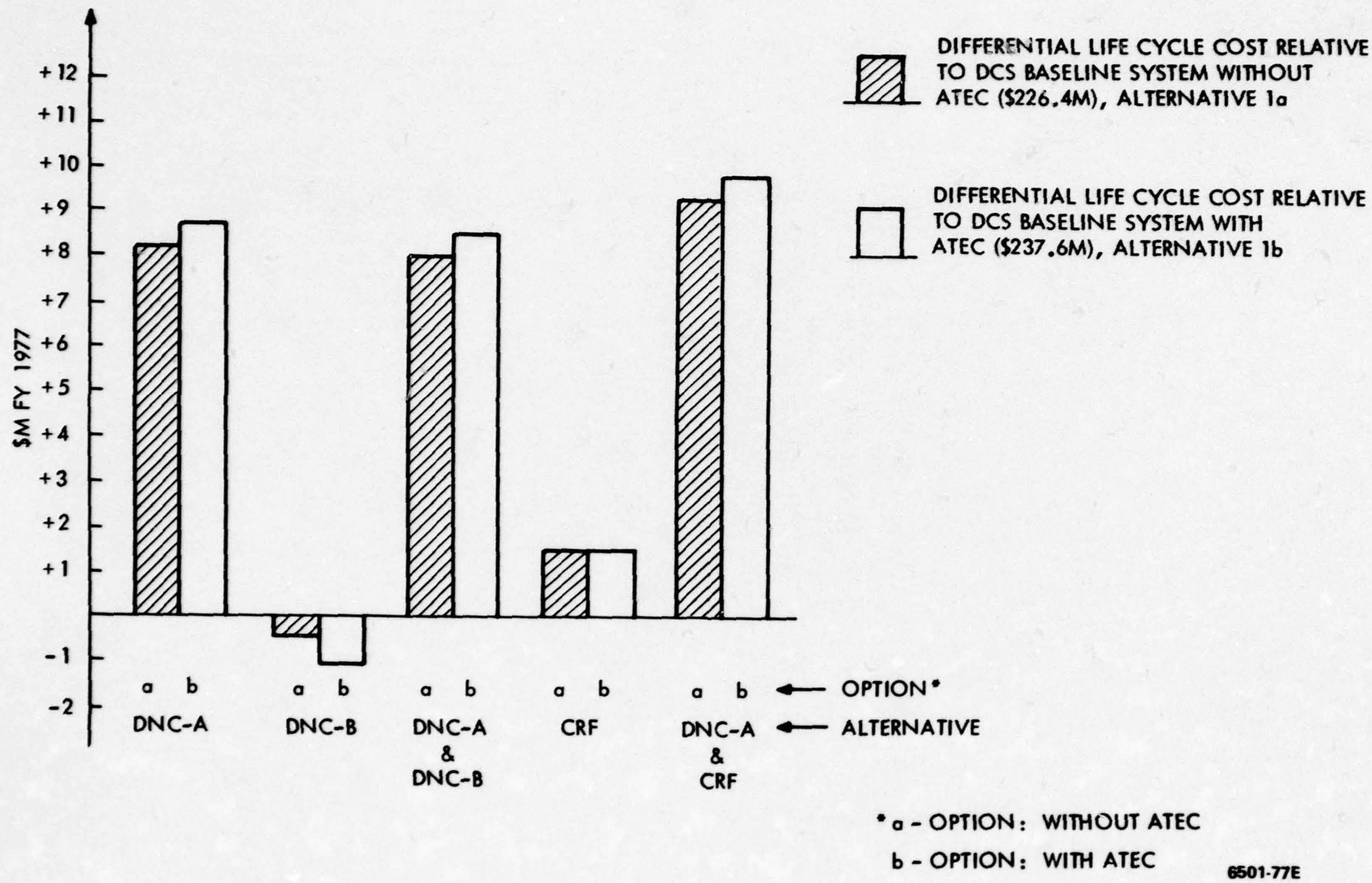

Figure 1-2. 10-Year Differential Life Cycle Costs for Case 1

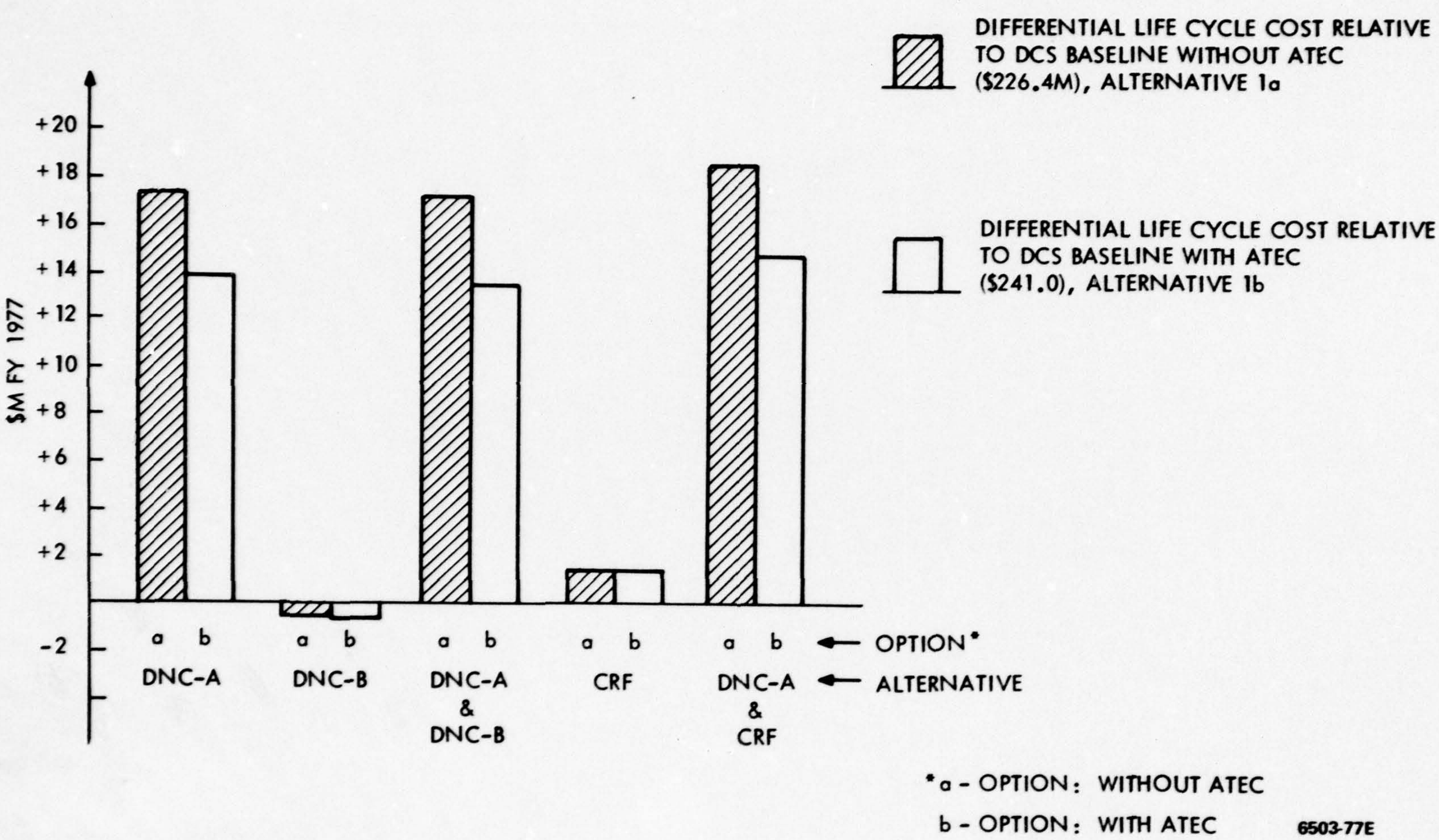

Figure 1-3. 10-Year Differential Life Cycle Costs for Case 2

Although DNC-A does not defray all costs associated with its deployment and operation over its life cycle, it can be expected to offset at least 46 percent of its costs assuming a manning level reduction given by the midpoint of the two manning cases. As discussed in section 5.3, DNC-A can be expected to exceed the baseline system by $10.9M which is only 4.6 percent of the baseline life cycle cost and can be compared to ATEC which results in a net cost increase over the baseline of at least $11.2M. In addition, consideration of DNC-A benefits which could not be costed, as discussed in section 5.3, provide the potential to make DNC-A completely cost effective.

As determined during the study, ATEC reduces the cost associated with the deployment of DNC hardware. However, the majority of the savings is not due to the decrease in cost associated with control hardware, but rather in the manner in which ATEC and DNC-A jointly act to reduce manning levels. The results indicate that the complementary capabilities of ATEC and DNC-A in the area of technical control automation (refer to Table 4-15) provides a combined reduction in life cycle cost such that the joint deployment of ATEC with DNC-A/DNC-B is likely to be more cost effective than either deployed alone.

Based on the results of the manning analysis it is concluded that the deployment of DNC-As to achieve a channel rerouting/reassignment capability less than full flexibility is not desirable. Although the cost of deployment and operating decreases with a lesser network flexibility, the benefits derived from DNC-A fall off almost completely with the other network flexibility alternatives (e.g., full interconnect, partial flexibility, etc.). Thus, both performance and cost considerations result in their elimination. The rules governing deployment for full flexibility as described in Reference 1 have not changed as a result of the study. However, the rules for deploying DNC-B in the network have changed extensively due to cost factors and tradeoffs determined in sections 3.2.3 and 3.2.4. The major conclusions are that DNC/B must now provide for interfacing individual channels and subchannels and that significant channel mileage saving can be obtained by judiciously replacing certain DNC-As with DNC-Bs.

Based on the first eight tasks, DNC has been demonstrated to provide significant operational and performance benefits which minimize, and in many cases eliminate, DCS control deficiencies. In Task 9, DNC-B has been shown to be the preferred interface to AUTOSEVOCOM II and, in fact, to be totally cost effective. DNC-A has been shown to significantly improve circuit availability. to complement the capabilities of ATEC making it more cost effective, and to offset a considerable portion of its development and deployment costs due to its automation capabilities in the technical control area. For these reasons, it is recommended that a DNC feasibility model be pursued to:

a. Verify the cost-effectiveness of DNC-B

b. Verify and further examine the impact of DNC-A on technical control automation and ATEC effectiveness

c. Quantify cost benefits specified in tasks one through eight, but which could not be considered in the present analysis due to the unavailability of data.

It is further recommended, as discussed in section 5.4, that a four-port multiplexer card be developed for the first level multiplexer as a means of realizing considerable cost savings in the AUTOSEVOCOM II interface.

SECTION 2
BASELINE DCS SYSTEM

2.1 SYSTEM DESCRIPTION

The DCS model described in this section establishes the baseline against which all DNC alternatives will be contrasted and compared. The DCS baseline system considered is a subset of the digital European theater as it would appear in the 1984-1993 time frame based on a continuation of present planning. It is felt that this cross section is sufficiently general to permit extension and application of the results obtained herein to other digital upgrades and networks.

The baseline system consists of digital transmission links planned under DEB stages 2 through 4, manual AUTOSEVOCOM II interface equipment, associated transmission technical control/system control, and related DCS manning. These facilities and personnel are required to accommodate the baseline transmission backbone and collocated AUTOSEVOCOM, AUTOSEVOCOM II, AUTOVON, AUTODIN and satellite equipment. It should be noted that the hardware associated specifically with the switch networks and satellite terminals is not considered in the baseline since it does not vary between the different DNC alternatives. Examples of equipment not included in the baseline are network circuit and message switches (AN/FTC-31s, AN/TTC-39s as part of AUTOSEVOCOM II, etc.), switch PTFs and TCFs, and satellite earth terminal facilities.

Because it is not possible to reassign channels in bulk encrypted digital groups [Reference 1, section 4-7], FKV and DEB stage 1 transmission facilities are not included in the baseline system. However, the results obtained here are directly applicable to these subnetworks through the incurred cost of replacing the CY-104s by separate multiplexers and KGs.

Figure 2-1 illustrates the baseline system connectivity. The network shown consists of 90 transmission nodes interconnected by 100 digital links. Twenty-nine of the 90 nodes are assumed to be unmanned, that is, there are no technical controllers or maintenance personnel permanently assigned. Additionally, 20 of the 61 manned locations are equipped with technical control facilities (technical controllers permanently assigned) and the remaining 41 stations have only

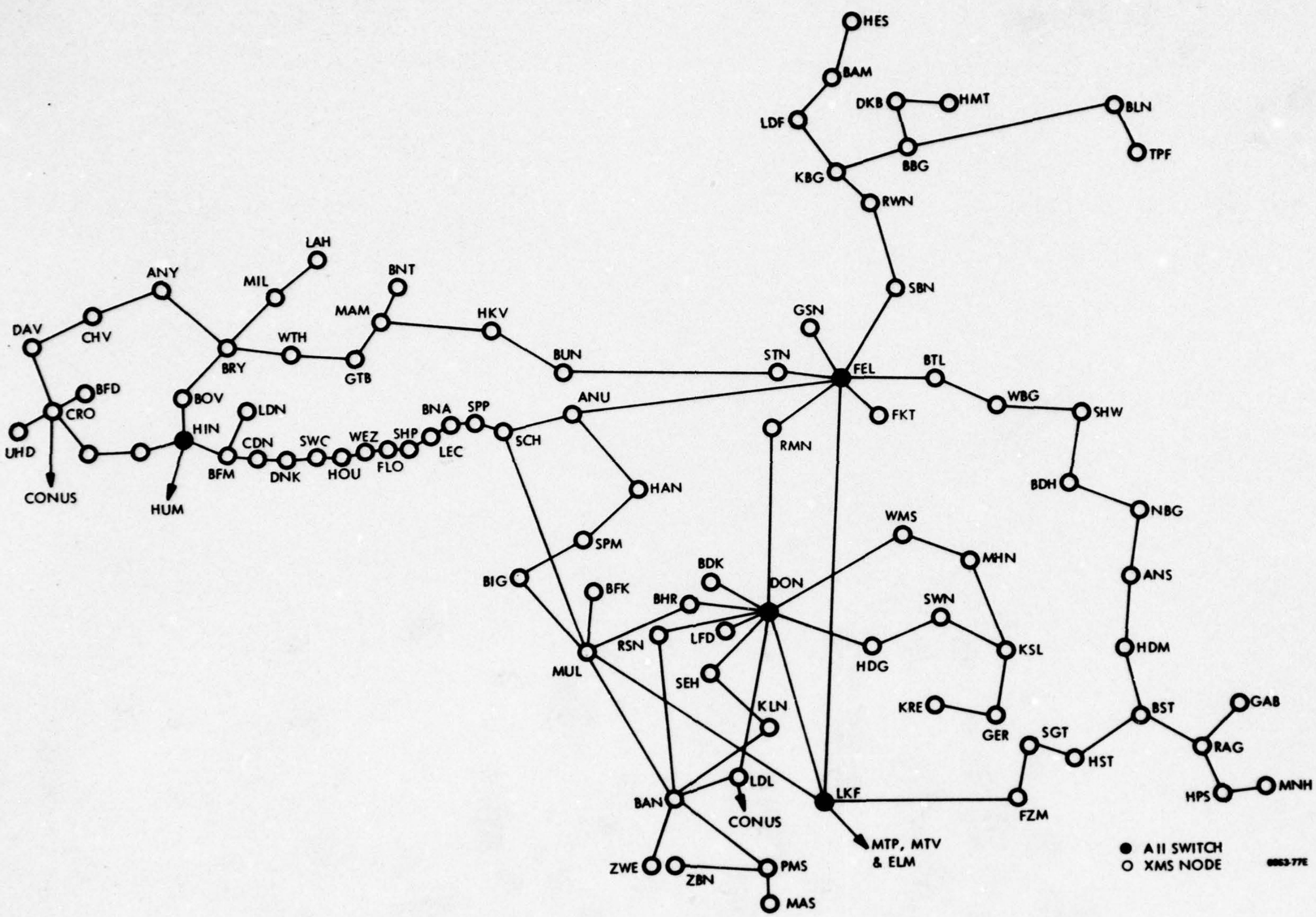

Figure 2-1. DCS Baseline System

maintenance personnel assigned on a permanent basis. This manning structure is based on a DCEC provided manning data base (Reference 2) and the DEB multiplex plans (Reference 3). A detailed description of the baseline manning is given in section 4.2.1.

ATEC equipment deployment in the baseline system consists of 3 sectors, 9 nodes and 59 stations. The AUTOSEVOCOM II complement within the baseline system consists of 4 AN/TTC-39s and 25 digital concentrators. The following subsections examine the components of the baseline system in greater detail.

2.1.1 Baseline Transmission Network

The transmission network shown in Figure 2-1 traverses Great Britian, Belgium, Netherlands and Germany. It consists of previously existing analog links upgraded to a digital capability during DEB stages 2 through 4 or new digital links installed at that time. The basic unit of transmission in the network is the 64-kb/s PCM channel. The components of the transmission equipment hierarchy are shown in Figure 2-2 and will be procured under project DRAMA. Also shown in this figure are the various users of the transmission network. It should be noted that the TD-1192 first level multiplexer provides both VF and digital data access to the transmission network, however, level A or level B submuxes (Reference 4, Appendix A) are required to efficiently utilize the PCM channels at rates below 64 kb/s. It is assumed that in the time frame being considered, 1984-1993, a synchronous timing system will be available on a network-wide basis. Such a timing system is required for each of the DNC alternatives for reasons detailed in Reference 1, section 4.4.2. Because of the uncertainty in the manner in which this synchronous timing system will be implemented, its acquisition and operating and maintenance costs have been omitted from the baseline life cycle cost calculations. This does not, however, affect either the ranking of the DNC alternatives or their respective life cycle costs, since the timing subsystem is required regardless of DNC application.

Table 2-1 is an overall equipment and manpower summary for the baseline system. The information is derived from References 2, 3 and 5. The manning for satellite and switch facilities are assumed to be

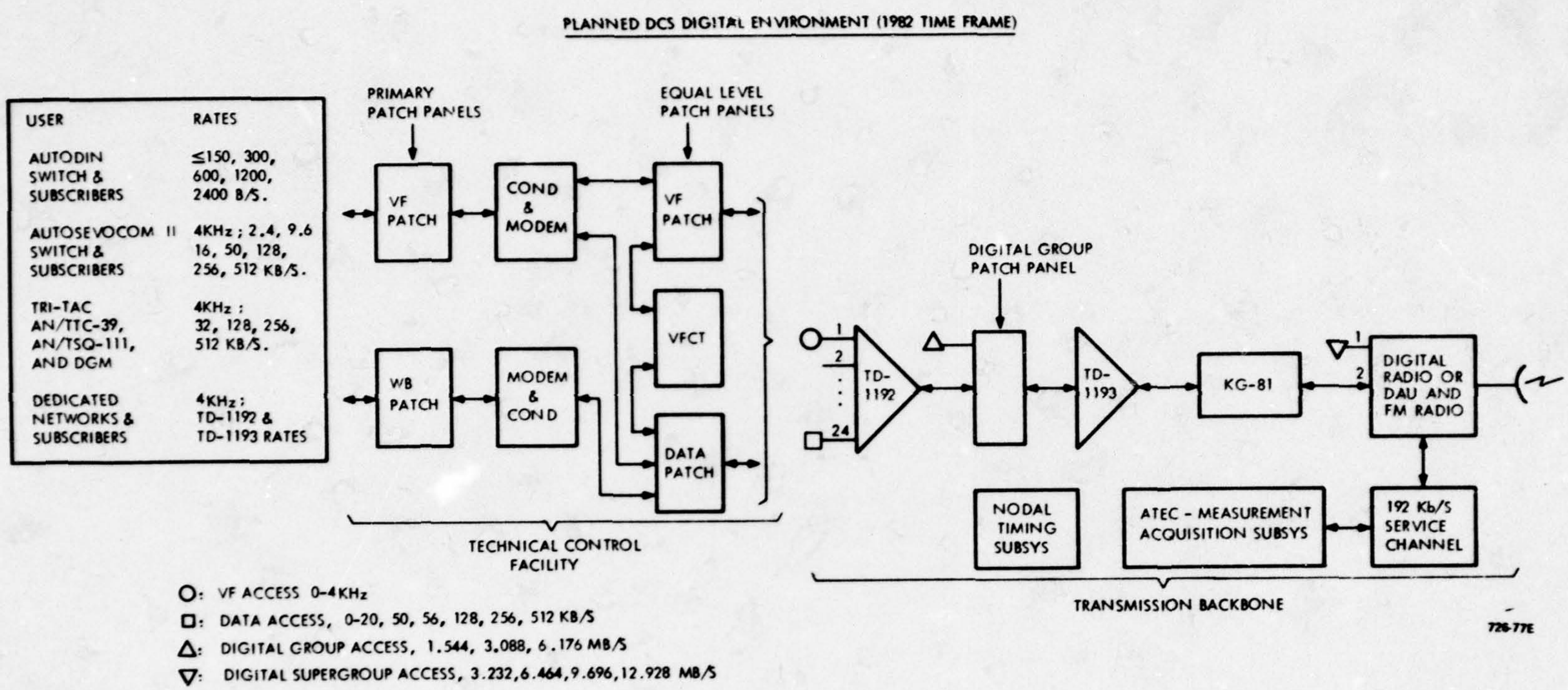

Figure 2-2. Baseline Transmission Configuration

TABLE 2-1. BASELINE EQUIPMENT AND MANNING SUMMARY

	STATION		TRANSMISSION EQUIPMENT							MANNING			
					TD-1193								
	NAME	CODE	KG-81	TD-1192	4	8	FRC-163	DEB LINKS	ANALOG LINKS	SAT.	SWITCH	TECH CONTROL	MAIN-TENANCE
1	Adenau	ANU	6	0	0	6	3	3	2	0	0	0	0
2	Alconbury	ANY	2	3	0	2	2	2	2	0	0	0	10
3	Ansbach	ANS	4	4	0	4	2	2	*	0	0	0	4+
4	Bakreuznach	BDK	1	3	1	0	1	1	1	0	0	0	7
5	Badmunder	BAM	2	2	2	0	2	2	*	0	0	0	4+
6	Bann	BAN	10	32	0	10	6	6	6	0	0	12	6
7	Barford St. John	BFD	1	3	1	0	1	1	2	0	0	0	0
8	Barkway	BRY	6	0	0	6	4	4	4	0	0	0	0
9	Baumholden	BHR	4	3	0	4	2	2	1	0	0	0	12
10	Ben Ahin	BNA	0	0	0	0	2	2	2	0	0	0	0
11	Bentwaters	BNT	1	2	1	0	1	1	3	0	0	0	2
12	Berlin	BLN	2	6	2	0	2	2	4	0	5	9	12
13	Bitburg	BIG	4	4	0	4	2	2	1	0	0	0	12
14	Bocksberg	BBG	1	0	2	1	3	3	3	0	0	0	5
15	Boerfink	BFK	1	7	0	1	1	1	0	0	0	0	4+
16	Bonstetten	BST	6	0	0	6	3	3	2	0	0	0	0
17	Botley Hill Farm	BFM	3	0	0	3	3	3	3	0	0	0	0
18	Bovingdon	BOV	0	0	0	2	2	2	2	0	0	0	0
19	Brandhof	BDH	0	0	0	2	2	2	2	0	0	0	0
20	Breitol	BTL	4	2	0	4	2	2	6	0	0	0	7
21	Bruggen	BUN	2	2	0	2	2	2	2	0	0	0	4+
22	Chelveston	CHV	0	0	0	0	2	2	2	0	0	0	0
23	Christmas Common	CRS	0	0	0	0	2	2	2	0	0	0	0
24	Cold Blow	CDW	2	1	0	2	2	2	2	0	0	0	4+
25	Croughton	CRO	4	17	2	2	4	4	8	0	135	12	13
26	Daventry	DAV	0	0	0	0	2	2	2	0	0	0	0
27	Donnersberg	DON	17	50	0	17	10	10	17	0	29	10	16
28	Drackenberg	DKB	0	0	0	0	2	2	2	0	0	0	0
29	Dunkirk	DNK	0	0	0	0	2	2	2	0	0	0	0
30	Feldberg	FEL	13	47	1	12	8	8	9	0	27	16	14

*: NOT SPECIFIED
+: ESTIMATED

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TABLE 2-1. BASELINE EQUIPMENT AND MANNING SUMMARY (Cont.)

	STATION		TRANSMISSION EQUIPMENT							MANNING			
					TD-1193								
	NAME	CODE	KG-81	TD-1192	4	8	FRC-163	DEB LINKS	ANALOG LINKS	SAT.	SWITCH	TECH CONTROL	MAIN-TENANCE
31	Flobecq	FLO	0	0	0	0	2	2	3	0	0	0	0
32	Frankfurt	FKT	2	16	0	2	1	1	6	0	6	0	2
33	Friozhelm	FZM	0	0	0	0	2	2	2	0	0	0	0
34	Gablingen	GAB	1	4	0	1	1	1	1	0	0	0	10
35	Geissen	GSN	1	3	1	0	1	1	1	0	0	0	6
36	Germersheim	GER	2	3	0	2	2	2	*	0	0	0	4+
37	Great Bromley	GTB	0	0	0	0	2	2	2	0	0	0	0
38	Hann	HAN	4	5	0	4	2	2	1	0	0	0	12
39	Heidelberg	HDG	4	23	0	4	2	2	5	0	30	10	2
40	Heidenheim	HDM	0	0	0	0	2	2	2	0	0	0	0
41	Helmstedt	HMT	1	1	1	0	1	1	1	0	0	0	6
42	Hess.-Oldendorf	HES	1	1	1	0	1	1	*	0	0	0	4+
43	High Wycome	HYE	2	2	0	2	2	2	2	0	0	0	4+
44	Hillingdon	HIN	5	32	0	5	3	3	5	0	36	20	17
45	Hoek Van Holland	HKV	0	0	0	0	2	2	2	0	0	0	0
46	Hohen Peiss.	HPS	0	0	0	0	2	2	2	0	0	0	0
47	Hohenstadt	HST	4	12	0	4	2	2	8	0	0	0	3
48	Houten	HOU	0	0	0	0	2	2	2	0	0	0	0
49	Kaiserlautern	KLN	4	18	0	4	2	2	1	0	0	10	12
50	Karlsruhe	KRE	1	4	0	1	1	1	1	0	0	0	7
51	Koenigstuhl	KSL	4	12	0	4	3	3	6	0	0	5	6
52	Koterberg	KBG	5	0	0	5	3	3	2	0	0	0	0
53	Lakenheath	LAH	1	4	0	1	1	1	1	0	0	0	4
54	Landstuhl	LDL	3	11	0	3	2	2	2	46	0	7	8+
55	Langerkopf	LKF	7	24	0	7	4	4	4	0	27	26	16
56	Lechenoi	LEC	0	0	0	0	2	2	2	0	0	0	0
57	Liderhof	LDF	4	7	1	3	3	3	3	0	0	0	4
58	Lohnfeld	LFD	1	2	1	0	1	1	2	0	0	0	14
59	Mannheim	MHN	2	5	0	2	2	2	2	0	0	0	4+
60	Martlesham Heath	MAM	4	17	0	4	3	3	4	0	19	18	17

*: NOT SPECIFIED
+: ESTIMATED

6642-77E

TABLE 2-1. BASELINE EQUIPMENT AND MANNING SUMMARY (Cont.)

	STATION		TRANSMISSION EQUIPMENT							MANNING			
					TD-1193								
	NAME	CODE	KG-81	TD-1192	4	8	FRC-163	DEB LINKS	ANALOG LINKS	SAT.	SWITCH	TECH CONTROL	MAIN-TENANCE
61	Masweiller	MAS	1	4	1	0	1	1	*	0	0	0	4+
62	Mildenhall	MIL	2	8	0	2	2	2	5	0	2	4	2
63	Muhl	MUL	11	21	0	11	6	6	6	0	0	7	10
64	Munich	MNH	1	4	0	1	1	1	1	0	0	0	7
65	Navy London	LDN	1	4	0	1	1	1	5	0	0	0	4+
66	Nuerberg	NBG	4	10	0	4	2	2	2	0	0	0	6
67	Pirmasens	PMS	5	19	1	4	3	3	7	0	135	20	29
68	Ramstein	RSN	4	24	0	4	2	1	2	0	13	17	20
69	Reese Augs.	RAG	4	7	0	4	3	3	3	0	0	0	17
70	Rein Mein	RMN	2	3	0	2	2	2	2	0	0	6	27
71	Roth Western	RWN	0	0	0	0	2	2	2	0	0	0	0
72	Schoenfeld	SCH	6	37	0	6	3	3	9	0	24	6	4
73	Schwanberg	SHW	0	0	0	0	2	2	2	0	0	0	0
74	Schwarzenborn	SBN	0	0	0	0	2	2	2	0	0	0	0
75	Schwetzingen	SWN	2	2	0	2	2	2	2	0	0	0	5
76	Sembach	SEH	4	7	0	4	2	2	2	0	4	16	0
77	Shape	SHP	4	11	0	4	2	2	2	0	2	0	7
78	Spa Malchamps	SPP	0	0	0	0	2	2	2	0	0	0	0
79	Spangdahlem	SPM	4	5	0	4	2	2	1	0	0	0	12
80	Stein	STN	2	2	0	2	2	2	10	0	0	0	3
81	Stuttgart	SGT	4	14	0	4	2	2	5	0	0	4	4
82	Swingate	SWG	0	0	0	0	2	2	2	0	0	0	0
83	Templehof	TPF	1	2	1	0	1	1	1	0	0	0	6
84	Upper Heyford	UHD	1	3	1	0	1	1	2	0	0	0	0
85	Westrozebeke	WFZ	0	0	0	0	2	2	2	0	0	0	0
86	Wethersfield	WTH	2	2	0	2	2	2	2	0	0	0	3
87	Worms	WMS	2	4	0	2	2	2	1	0	0	0	10
88	Wurzburg	WBG	2	5	0	2	2	2	1	0	0	0	10
89	Zweibrucken-A	ZBN	1	4	1	0	1	1	1	0	0	0	5
90	Zweibrucken-AF	ZWE	1	1	1	0	1	1	1	0	0	0	5

*: NOT SPECIFIED
+: ESTIMATED

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the same for the DEB network as for the present analog network. That is, the digital upgrade does not affect their manpower allocation. Technical controllers and maintenance personnel at DEB locations are derived from the analog data base by assigning DEB personnel in the same ratio as the number of digital links to analog links. For example, if a station presently has 8 analog links which are attended by 10 technical controllers and 12 maintenance men, and if the digital upgrades result in 4 digital links, the manning associated with the digital links is assumed to be half of what is required for the analog links, that is, 5 technical controllers and 6 maintenance personnel. Inherent in this manning approach is the assumption that the technical controller and maintenance workload for digital links will be the same as for the present analog links. Although it was felt that this approach would probably over estimate manning for the baseline system, the lack of manning data for digital links made this approach the only viable one. It should be noted that this assumption does not affect evaluation of the DNC alternatives since they are concerned with manpower variations around the baseline.

As may be seen in Table 2-1, manning at several locations was estimated. This was made necessary by omissions and errors in the data base and the need to quantify contract labor. All estimates are based on manning averages for stations of similar size and are discussed further in section 4.2.1.

2.1.2 AUTOSEVOCOM II Interface to the Baseline

AUTOSEVOCOM II will provide a secure circuit switch service for the DoD. For the purposes of this study, AUTOSEVOCOM II is assumed to utilize AN/TTC-39s as the basic time division circuit switch operating in conjunction with digital concentrators serving a PABX function. The channel digitalization rate is 16 kb/s and all switch generated time division multiplexed trunk groups conform to TRI-TAC specifications (Reference 6) with respect to rate and format.

Figure 2-3 functionally illustrates the interface between AUTOSEVOCOM II and the transmission network for the baseline system. This manual interface is based on Reference 7 and is one of several being

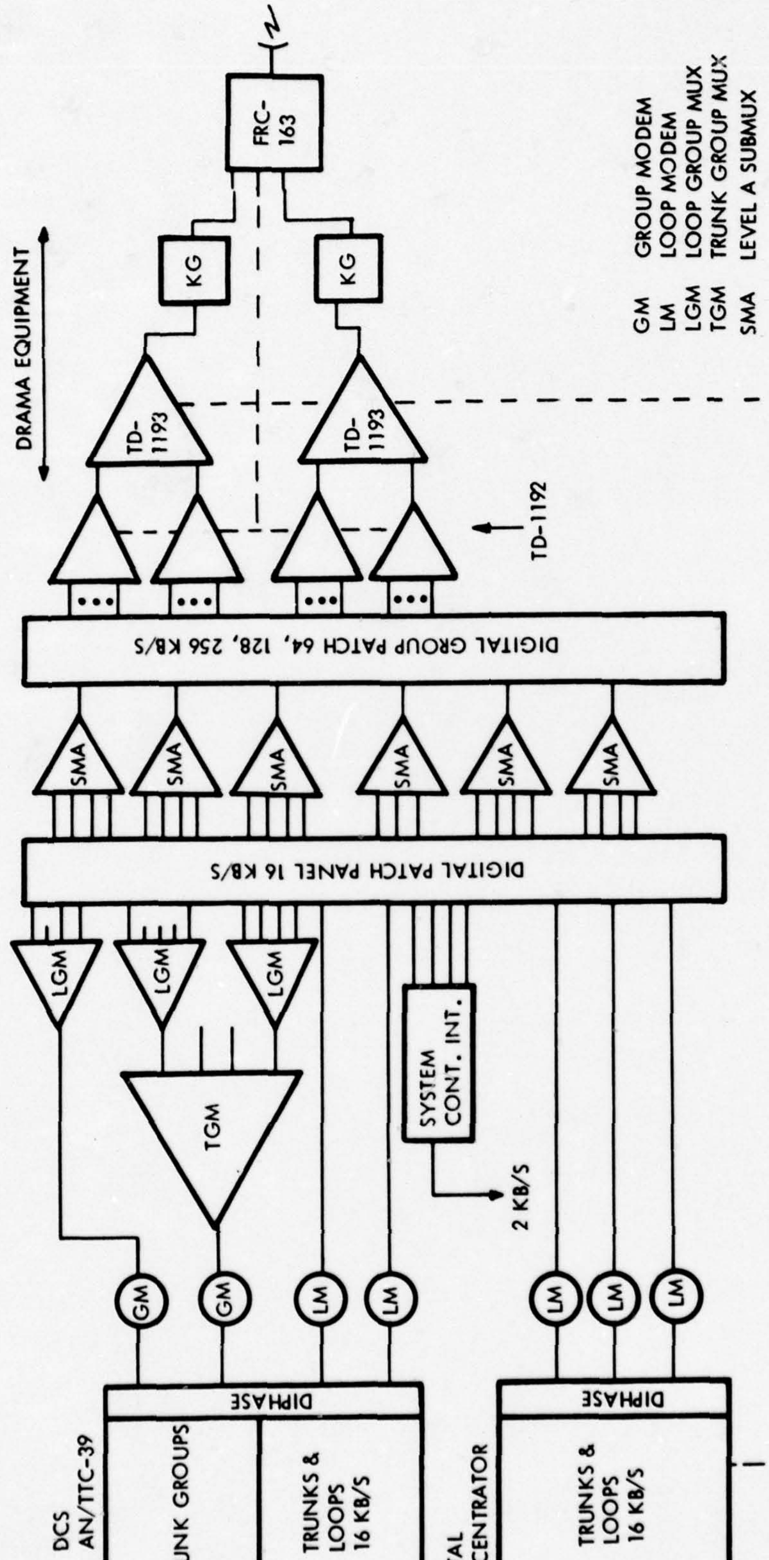

Figure 2-3. Baseline System AUTOSEVOCOM II/Transmission Interface

evaluated by DCEC. The results of this study will provide an effective means of comparing an automated alternative (DNC-B or CRF) to the manual interface. As shown in Figure 2-3, all trunk groups received from an AN/TTC-39 are demultiplexed to the channel level by the DGM family of multiplexers. Trunk groups are then reformed using level A submultiplexers and inputted to the first level multiplexer. It is assumed that all interswitch trunk groups are broken down to the channel level for technical control purposes; thus, the LGM and SMA maximum channel limitation of 16 16-kb/s channels precludes having any AUTOSEVOCOM II trunk groups with cross sections larger than 256 kb/s. The interface between the digital concentrator and the transmission network is at the 16-kb/s level thereby obviating the need for DGM multiplexers.

Access to the 2-kb/s subchannels within certain interswitch trunk group overhead channels is necessary for system control purposes. A system control interface unit is included in the baseline interface for this purpose as indicated in Figure 2-3. This device would provide the capability to drop and insert 2 kb/s subchannels at the technical control facility and to form 16-kb/s channels from subchannels for transmission to appropriate system control locations.

The AUTOSEVOCOM II network as analyzed comprises 4 AN/TTC-39s and 26 digital concentrators which are located within the baseline system shown in Figure 2-1. Digital concentrators located outside the baseline system are not considered; however, interswitch trunks to switches located outside the baseline are considered. Referring to Figure 2-1, access to the switch at Humosa is obtained via Hillingdon; access to the switches at Mt. Pateras, Mt. Vergine and Elmadag is obtained via Langerkopf; and access to CONUS is obtained via Croughton or Landstuhl.

Switch-to-switch and digital concentrator-to-switch trunking requirements provided by DCEC were used to manually generate AUTOSEVOCOM II routing in the network. This was necessitated by a lack of specific routing plans which is to be expected at such an early stage in the AUTOSEVOCOM II Program. The routing, in turn, determined the AUTOSEVOCOM II interface equipment required for the baseline system.

Implicitly assumed in the routing process was that only DEB was to be used to route intra-Europe requirements, and that local access lines are serviced by the patch and test facility associated with the switch. The routing was performed with the specific goal of utilizing the transmission capacity as efficiently as possible. In many cases this meant demultiplexing trunk groups at intermediate locations to improve fills. Although it was recognized that the resulting routing would probably not precisely reflect the actual routing, it was felt that the results would be sufficiently general to permit drawing valid conclusions with regard to automating the interface and estimating related life cycle costs. It is interesting to note that a similar approach is employed in Reference 8, section 3, to evaluate several AUTOSEVOCOM II interface alternatives.

Using the above routing approach, the equipment requirements obtained for the baseline system are shown in Table 2-2.

TABLE 2-2. BASELINE AUTOSEVOCOM II EQUIPMENT TOTALS

EQUIPMENT	SWITCH INTERFACE	CONCENTRATOR INTERFACE	INTERMEDIATE LOCATIONS	TOTAL
Group Modem	25			25
Loop Modem	169	169		338
Trunk Group Mux	4			4
Loop Group Mux				
8-Inputs	16			16
16-Inputs	20			20
Level A Submux				
4-Inputs	8	6	4	18
8-Inputs	16	12	6	34
16-Inputs	42	24	8	74
Syscon Interface Unit	4	26	5	35

2.1.3 ATEC Application to the Baseline

The application of ATEC to the DCS baseline system shown in Figure 2-1 will provide automated assistance to both technical controllers and maintenance personnel in many areas. The impact of this assistance

on overall baseline manning levels is examined in section 4.2.1. The purpose of this section is to describe the deployment and characteristics of ATEC hardware in the DCS baseline system. Additional background information on the relationship between system control, ATEC and DNC may be found in Reference 1, sections 2 and 3.

Using DCEC - supplied data, the expected deployment of ATEC hardware in the baseline system is as shown in Table 2-3. For all subsequent analyses, this is the assumed equipment allocation throughout the 1984-1993 time frame. Correlating the information in Table 2-3 with the information in Table 2-1 reveals that 22 of the 59 ATEC stations are radio repeater nodes. Another characteristic of the ATEC deployment which is required subsequently (section 4.2.1) is the breakdown of ATEC stations by size. The three classes of sizes considered along with the number of ATEC stations in each class, are as follows:

a. AUTOVON locations - 45 stations

b. Locations with greater than 300 long haul circuits, excluding AUTOVON locations - 8 stations

c. Locations with 300 or fewer long-haul circuits - 6 stations.

2.1.4 Uninstalled Equipment Costs

Important inputs to the cost benefits analysis of section 4 are the uninstalled costs for all equipments in the baseline system. Appendix A lists the assumed values for these costs and their source.

TABLE 2-3. ATEC DEPLOYMENT IN DCS BASELINE SYSTEM

SECTOR (SCS DEPLOYED)	SUBORDINATE NODES (NCS DEPLOYED)	SUBORDINATE STATIONS (MAS DEPLOYED)
Langerkopf	Donnersberg	Bann
		Donnersberg
		Kaiserlautern
		Landstuhl
		Ramstein
		Sembach
	Schoenfeld	Adenau
		Ben Ahin
		Flobecq
		Houtem
		Le Chenoi
		Schoenfeld
		Shape
		Spa Malchamps
		Westrozebeke
	Langerkopf	Boerfink
		Friolzheim
		Langerkopf
		Massweiller
		Muhl
		Pirmasens
Stuttgart	Feldberg	Feldberg
		Hoek Van Holland
		Rhein Mein
		Stein
	Koenigstuhl	Berlin
		Brandhof
		Brietol
		Frankfurt
		Heidelberg

TABLE 2-3. ATEC DEPLOYMENT IN DCS BASELINE SYSTEM (Cont.)

SECTOR (SCS DEPLOYED)	SUBORDINATE NODES (NCS DEPLOYED)	SUBORDINATE STATIONS (MAS DEPLOYED)
Stuttgart	Koenigstuhl	Koenigstuhl Mannheim Nuerberg Schwetzingen Schwanberg
	Stuttgart	Bonstetten Heidenheim Hohenspeissenberg Hohenstadt Munich Vaihingen
Hillingdon	Hillingdon	Botley Hill Farms Bovingdon Cold Blow Dunkirk Hillingdon London Navy Swingate
	Martlesham Heath	Barkway Great Bromley Martlesham Heath Mildenhall Wethersfeild
	Croughton	Chelveston Alconbury Christmas Common Croughton Daventry High Wycombe

SECTION 3

STUDY ALTERNATIVES - DEFINITION AND DEPLOYMENT

3.1 DNC BACKGROUND

The DCS baseline system to be evaluated was defined in section 2. This system includes a digital transmission backbone utilizing DRAMA equipment, a manual AUTOSEVOCOM II/transmission interface employing DGM and commercial multiplexers and modems, and an ATEC capability consistent with the final ATEC production system. In this section, five alternatives to the baseline system are defined. They are based on deployment (within the baseline) of the DNC-A function, the DNC-B function, and the channel reassignment function (CRF) of the AN/TSQ-11 (CNCE). An alternative predicated on modifying the CRF to emulate either the DNC-A or DNC-B functions is not considered; however, certain hardware and software modifications to the CRF have been assumed in order to 'commercialize' its implementation. As explained in section 3.2.5, this reduces its price and makes it cost competitive with the other DNC alternatives.

The functions, applications and engineering of DNC elements used in each alternative are based upon the results of the first eight tasks of the DNC study program, which are documented in Reference 1. Figures 3-1 and 3-2 illustrate the manner in which DNC and the CRF, respectively, are integrated into the transmission system and interface AUTOSEVOCOM II. In general, the DNC-A, DNC-B, and the CRF refer to an automated channel reassignment capability which is implemented using time division switching techniques.

The DNC-A function interfaces T1 digital groups and reassigns embedded 64-kb/s channels; the DNC-B function interfaces both T1 and TRI-TAC formatted digital groups and reassigns embedded 64/32/16-kb/s channels and 4/2-kb/s subchannels. The DNC-A function and the DNC-B function may be used in a stand alone mode (without the other) or in a dual configuration at site. Basic size modularity for the DNC-A is 32 T1 digital groups up to a maximum of 192, where each T1 group contains

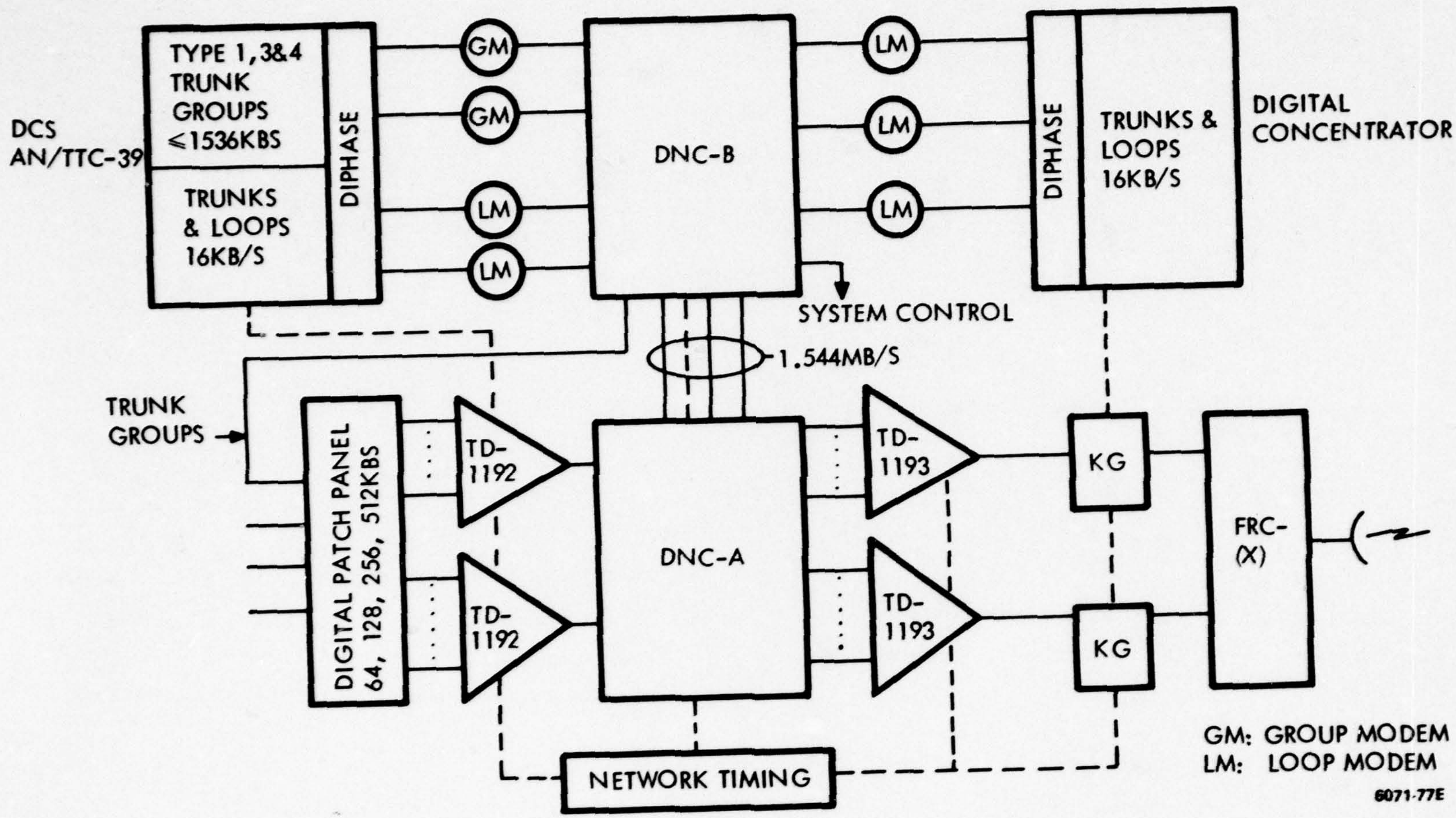

Figure 3-1. DNC AUTOSEVOCOM II/Transmission Interface

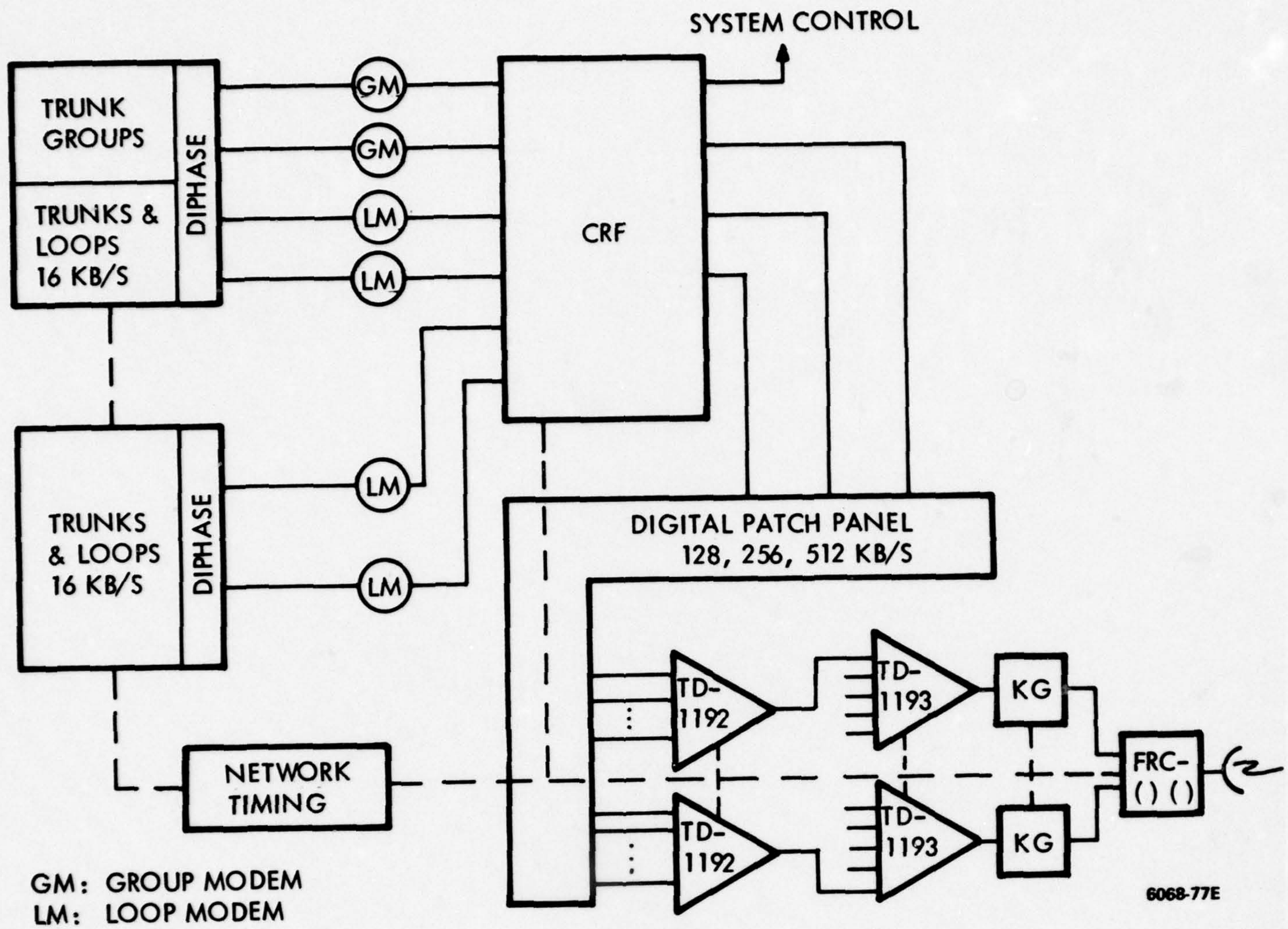

Figure 3-2. CRF AUTOSEVOCOM II/Transmission Interface

24 64-kb/s channels. Modularity for the DNC-B is more complex because TRI-TAC formatted trunk groups vary in the number of contained channels. Its basic modularity, however, is given by 15-25-40-50 digital group inputs or 6-12-18-24 internal multiplexed 1.544-kb/s digital groups. Additional detail on DNC modularity is given in Reference 1, section 6.2.1.

The CRF refers to an automated channel reassignment capability implemented from elements of the AN/TSQ-111 in accordance with Reference 9. The CRF is capable of reassigning channels and subchannels within TRI-TAC formatted digital groups only and, as such, its interface with the transmission network would be the channel side of the first level multiplexer. The CRF can be used in conjunction with the DNC-A function but not the DNC-B function. This is due to the fact that the DNC-B incorporates all CRF capabilities. It is interesting to note that although the DNC-B is primarily intended to interface the transmission network at the output of the first level multiplexer, it is also capable of interfacing at the input to the first level multiplexer. The benefits derived from this dual capability are exploited and discussed in section 3.2.5.

3.2 DEFINITION OF ALTERNATIVES

The specific alternatives to be evaluated with respect to life cycle cost are listed in Table 3-1. In addition, alternatives 2 through 6 will be examined with respect to the cost benefits they provide over the baseline system. As required by the SOW, each alternative will be considered both without and with a supporting ATEC deployment. This is denoted by the "a" and "b" options, respectively, in Table 3-1.

It should be realized that the baseline system defined in section 2 does not include all equipment and manpower that would actually be deployed at those DCS stations. Accordingly, the life cycle cost derived for the baseline system is not intended to be absolute measure of its actual life cycle cost. It is intended instead to yield an indication or gauge against which to measure and weigh the cost benefits obtained for each of the DNC alternatives.

TABLE 3-1. STUDY ALTERNATIVES

ALTERNATIVE	OPTION	DEFINITION
1. Baseline	a	The DCS Baseline System
	b	The DCS Baseline System Augmented by ATEC
2. DNC-A	a	The DCS Baseline System Augmented by DNC-A only
	b	The DCS Baseline System Augmented by ATEC and DNC-A
3. DNC-B	a	The DCS Baseline System Augmented by DNC-B only
	b	The DCS Baseline System Augmented by ATEC and DNC-B
4. DNC-A/DNC-B	a	The DCS Baseline System Augmented by DNC-A and DNC-B
	b	The DCS Baseline System Augmented by ATEC, DNC-A and DNC-B
5. CRF	a	The DCS Baseline System Augmented by CRF only
	b	The DCS Baseline System Augmented by ATEC and CRF
6. DNC-A/CRF	a	The DCS Baseline System Augmented by DNC-A and CRF
	b	The DCS Baseline System Augmented by ATEC, DNC-A and CRF

Note: The DCS Baseline System denotes equipment and manpower specified in sections 2.1.1 and 2.1.2.

The following subsections described in detail the deployment of hardware for alternatives 2 through 6.

3.2.1 DNC Optimization Considerations

In order that meaningful results are obtained from the cost benefits analysis, it is necessary that each DNC alternative be optimized with respect to the conceptual design of the hardware and the deployment of this hardware within the baseline system. During the first eight tasks of the study, DCS functional requirements and operational considerations were used to arrive at the most operationally effective implementation. Additionally, the limited life cycle cost analysis performed during the "Illustrative Application" task of the study implied that full flexibility deployment of DNC hardware would for the majority of situations, be the most cost-effective of the five possible DNC deployment schemes (refer to Reference 1, section 4.3, for a thorough discussion of DNC deployment alternatives). However, applying the design and deployment results obtained during the first eight tasks directly to baseline system does not necessarily ensure that DNC is being optimally applied to this representative cross section of the future digital DCS. This follows since the chosen design and deployment are now not only being evaluated in terms of operational considerations, but also in terms of the full cost of ownership (life cycle cost) and their impact on equipment, manpower and circuit mileage cost savings.

The approach to be used to ensure optimality of DNC application to the baseline is as follows. First the recommended design and deployment obtained during the first eight tasks are applied to each alternative. During this process any design changes which reduce equipment costs or increase cost benefits are evaluated immediately since this can be performed independently of the life cycle cost analysis. The requirements for and the results of any equipment modifications are discussed within each of the "alternative deployment" sections (3.2.2 to 3.2.6). Next, the cost benefits analyses are performed and the sensitivity of the results to variations in manpower, equipment and circuit mileage savings is determined. This provides the means to

evaluate the optimality of the chosen deployment scheme, fundamental hardware changes (such as incorporating the first-level multiplexer into the DNC function), and the impact of DNC availability on system cost. These results are discussed in section 5.2.

3.2.2 DNC-A Deployment/Alternative 2

As discussed in section 3.2.1, DNC-A deployment will provide a full flexibility capability. With this deployment, a network controller (NCS if ATEC equipped), or a technical controller via a network controller can, during unstressed conditions, establish a channel between any two first level multiplexer ports in the network. This permits a general circuit rerouting/reconfiguration capability without the need for manual patching. During stressed conditions, the same capability exists except where the reroute involves a circuit with a local loop failure or first level multiplexer failure, or a station which has become isolated from the rest of the next network. During these cases, remote and even manual rerouting may or may not be possible depending upon the extent of the failure. Quantification of the impact of stress conditions on DNC rerouting capability is examined in section 4.2.1.

To provide a full flexibility capability, DNC-A hardware is required at all baseline stations except non-branching repeaters and one-link terminal stations. In addition, all stations with DNC-A hardware and the T1 digital groups which pass through that hardware must form a connected graph where the stations are nodes and the T1 digital groups edges. The physical hardware which is deployed at each DNC-A equipped station is the interface and reassignment group-A (IRGA) and the common equipment group (CEG). This equipment is extensively described in Reference 1, section 7. All DNC hardware will employ the additional redundancy design so that availability meets the requirements established in Reference 1, section 4.6. The allocation of DNC hardware in the baseline system in order to achieve full flexibility is shown in Table 3-2. This is obtained by applying the full

flexibility deployment rules discussed above to the network topology shown in Figure 2-1. Implicit in this application is that the T1 digital group routing is as specified in DEB multiplex plans, Reference 3. A listing of the T1 digital groups used to achieve the connected graph requirement is given in Table 3-3.

Control of DNC-A hardware for alternatives 2a and 2b is discussed in section 4.2.3. It is interesting to note, however, that of the 43 baseline stations which are DNC-A equipped, 30 are also ATEC equipped (MAS elements are deployed).

In Alternative 2, interfacing AUTOSEVOCOM II is accomplished manually as in Alternative 1 (baseline system). As discussed previously, without the deployment of DNC-B, DNC-A does not automate the AUTOSEVOCOM II interface. Thus, the hardware required to achieve this interface is the same as specified, in Table 2-2.

With respect to Alternative 2, the functions and capabilities of DNC-A hardware were found to be well suited to the requirements imposed by the network; thus, no design changes were necessary.

3.2.3 DNC-B Deployment/Alternative 3

Application of DNC-B to the baseline provides for automation of the AUTOSEVOCOM II interface but does not provide any significant improvement in network reconfiguration flexibility. The potential cost benefits from DNC-B are reduced equipment quantities and reduced channel circuit miles. The deployment rules for DNC-B require that each AUTOSEVOCOM II AN/TTC-39 be interfaced by DNC-B hardware and that digital concentrators be examined on an individual basis to determine the effectiveness of a DNC-B interface. The physical hardware which is deployed at each DNC-B equipped station is the interface and reassignment group-B (IRGB) and the common equipment group (CEG). A summary of the equipment allocated to the baseline stations under Alternative 2 is given in Table 3-4.

TABLE 3-2. DNC-A HARDWARE DEPLOYMENT FOR FULL FLEXIBILITY (ALTERNATIVE 2)

STATION CODE[1]	DNC-A IRGA SIZE 32	64	96	128	DNC-A CEG	ATEC EQUIPPED	STATION CODE[1]	DNC-A IRGA SIZE 32	64	96	128	DNC-A CEG	ATEC EQUIPPED
1 ANY	1				1	X	28 MUL		1			1	X
2 ANS	1				1		29 NBG	1				1	X
3 BAM	1				1		30 PMS		1			1	X
4 BAN		1			1	X	31 PAG	1				1	
5 BHR	1				1		32 RMN	1				1	X
6 BLN	1				1	X	33 RSN		1			1	X
7 BIG	1				1		34 SCH			1		1	X
8 BTL	1				1	X	35 SGT	1				1	X
9 BUN	1				1		36 SHP	1				1	X
10 CDW	1				1	X	37 SWN	1				1	X
11 CRO		1			1	X	38 SEH	1				1	X
12 DON				1	1	X	39 SPM	1				1	
13 FEL			1		1	X	40 STN	1				1	X
14 GER	1				1		41 WTH	1				1	X
15 HAN	1				1		42 WMS	1				1	
16 HDG		1			1	X	43 WBG	1				1	
17 HIN			1		1	X	Totals	30	9	3	1	43	30
18 HST	1				1	X							
19 HYE	1				1								
20 KLN		1			1	X							
21 KSL	1				1	X							
22 LDF	1				1								
23 LDL	1				1	X							
24 LKF		1			1	X							
25 MHN	1				1	X							
26 MAM		1			1	X							
27 MIL	1				1	X							

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[1] See Table 2-1 for Station Code Identification

TABLE 3-3. T1 DIGITAL GROUPS USED TO COMPLETE CONNECTED GRAPH FOR FULL FLEXIBILITY

1	CRO-HYE	27	LDF-BAM
2	HYE-HIN	28	LDF-BLN
3	HIN-CDW	29	FEL-BTL
4	CDW-SHP	30	BTL-WBG
5	SHP-SCH	31	WBG-NBG
6	SCH-MUL	32	NBG-ANS
7	MUL-LKF	33	ANS-RAG
8	LKF-DON	34	FEL-RMN
9	DON-RSN	35	RMN-DON
10	RSN-BAN	36	DON-WMS
11	DON-LDL	37	WMS-MHN
12	LDL-BAN	38	MHN-KSL
13	BAN-DMS	39	KSL-GER
14	PMS-LKF	40	KSL-SWN
15	LKF-FZM	41	SWN-HDG
16	FZM-SGT	42	HDG-DON
17	SGT-HST	43	DON-SEH
18	CRO-ANY	44	SEH-KLN
19	ANY-HIN	45	KLN-BAN
20	HIN-MIL	46	BAN-BMS
21	HIN-WTH	47	DON-BHR
22	WTH-MAM	48	MUL-BHR
23	MAM-BUN	49	BHR-SPM
24	BUN-STN	50	SPM-HAN
25	STN-FEL	51	HAN-SCH
26	FEL-LDF	52	SCH-FEL

TABLE 3-4. DNC-B/AUTOSEVOCOM II HARDWARE DEPLOYMENT SUMMARY

Location	EQUIPMENT QUANTITIES ③											
	GM	LM	LGM-		SMA-			SIU	IRGB			CEG
			8	16	4	8	16		6	12	18	
Hillingdon	1	22	0	0	0	0	0	0	1	0	0	1
Feldberg	1	13	0	0	0	0	0	0	0	1	0	1
Lankerkopf	2	49	0	0	0	0	0	0	0	1	0	1
Donnersberg	2	85	0	0	0	0	0	0	0	1	0	1
Digital Concentrators ①	0	169	0	0	3	14	24	26	0	0	0	0
Other ②	0	0	0	0	4	4	11	5	0	0	0	0
Totals	6	338	0	0	7	18	35	31	1	3	0	4

Notes:

① 26 Digital Concentrator Locations

② Branching or Rechannelization Sites

③ LM: Loop Modem
GM: Group Modem
LGM: Loop Group Multiplexer
SMA: Level A Submultiplexer
IRGB: Interface and Reassignment Group B
CEG: Common Equipment Group
SIU: System Control Interface Unit

The routing of requirements used to obtain Table 3-4 is the same used for the manual AUTOSEVOCOM II interface; however, the total channel miles required for the DNC-B alternative is significantly less. Specifically, 83533 channel-miles are required for the manual approach (Alternative 1) and 76565 for the DNC-B approach, a decrease of 8.3 percent. This reduction stems from the greater efficiency with which DNC-B is able to use transmission capacity. For example, the manual interface is constrained in many cases to route in groups, of 8 or 16 AUTOSEVOCOM II channels, whereas, routing between DNC-B locations can always be in groups of 4 channels.

The capability to realize greater transmission efficiency through the deployment of DNC-B provides a tradeoff between hardware and circuit miles. This tradeoff was used to achieve the deployment which resulted in Table 3-4. Further, it was determined that the

basic acquisition cost to deploy DNC-B hardware at locations other than AN/TTC-39's locations was not offset by the reduced number of multiplexers and modems or the decrease in total circuit miles.

As a result of the DNC-B deployment analysis, it became apparent that a modification to the IRGB design was necessary in order that its AUTOSEVOCOM II interface could be made more cost effective. Previously, the IRGB accepted only digital group inputs (i.e., 128 kb/s to 1.544 Mb/s). Thus, multiplexers were required to interface trunks from a digital concentrator or an AN/TTC-39. Since this multiplexing function could be incorporated into the IRGB with minimum hardware and software alterations, and yield a resulting decrease in cost over separate multiplexers, the change was instituted. The modified DNC-B permits the direct input of up to 94 16-kb/s channels and 16 2-kb/s channels, or up to 47 32-kb/s channels and 8 4-kb/s subchannels. This quantity of circuit inputs is sufficient to handle the largest expected requirement.

The impact of the added multiplexing capability on DNC-B production costs has been computed and the new costs are used in all subsequent calculations. Appendix A provides an undated DCE Cost Summary for IRGB and CEG Configuration, which is Table 9-2 of Reference 1. Figure 3-1 also reflects this change.

Control of DNC-B hardware for Alternatives 3a and 3b is discussed in section 4.2.3.

3.2.4 DNC-A, DNC-B Joint Deployment/Alternative 4

The deployment of DNC hardware in Alternative 4 is subject to the same requirements and follows the same procedures used in Alternatives 2 and 3. Based on the results of Alternative 2, 43 locations require DNC-A hardware in order to achieve full flexibility; based on Alternative 3, each of the four AN/TTC-39 sites requires DNC-B hardware. Thus, only the AN/TTC-39 sites would have DNC-A and DNC-B jointly deployed. However, additional cost benefits can be realized in the joint deployment by equipping some of the DNC-A only stations which also have digital concentrators with DNC-B hardware instead. This results in even greater transmission efficiency than obtained in Alternative 2. The total number of AUTOSEVOCOM II channel miles

required for Alternative 4 is 73197, a decrease of 12.4 percent over the baseline system. At those sites where DNC-A hardware is replaced by DNC-B hardware, the DNC-B is not only performing an AUTOSEVOCOM II interface function but is also fulfilling the full flexibility requirements. Table 3-5 gives the equipment summary for Alternative 4.

During the analysis, it was determined that additional channel miles could be saved if several other DNC-A sites were equipped with DNC-B hardware instead. However, the maximum size limitation of the IRGB precluded this replacement. Because of the limited number of sites and channel miles involved, a tradeoff analysis revealed that redesigning the DNC-B to accept a larger number of trunk groups was not warranted.

Control of DNC hardware for Alternatives 4a and 4b is examined in section 4.2.3. As in Alternative 2, 30 of the 43 DNC-equipped stations are also ATEC equipped.

TABLE 3-5. DNC-A/DNC-B/AUTOSEVOCOM II HARDWARE DEPLOYMENT SUMMARY

	EQUIPMENT QUANTITIES															
			LGM-		SMA-				IRGB			IRGA				CEG
Location	GM	LM	8	16	4	8	16	SIU	6	12	18	32	64	96	128	
DNC-A Sites	0	149	0	0	6	10	17	0	0	0	0	25	8	1	0	34
DNC-B Sites	0	21	0	0	0	0	0	0	2	3	0	0	0	0	0	5
DNC-A/DNC-B Sites	6	129	0	0	0	0	0	0	4	0	0	0	1	1	2	4
Others	0	39			0	7	5	10	0	0	0	0	0	0	0	0
Totals	6	338	0	0	6	17	22	10	6	3	0	25	9	2	2	43

Legend:

GM - Group Modem

LM - Loop Modem

LGM - Loop Group Multiplexer

SMA - Level A Submultiplexer

SIU - System Control Interface Unit

IRGA - Interface and Reassignment Group A

IRGB - Interface and Reassignment Group B

CEG - Common Equipment Group

3.2.5 CRF Deployment/Alternative 5

As used in this document, the CRF denotes hardware capable of performing only the channel reassignment functions specified in the TRI-TAC CNCE performance specification listed in Reference 9. Presently, no such single piece of hardware exists. Implementation of a CRF directly from the CNCE system would require modification of the timing, synchronization and power distribution networks, and extraction and modification of various elements of the Patch and Test Subsystem, Processor Subsystem, and Control Communications Subsystem. Further, extensive mechanical, electrical and software redesign would be necessary to integrate all the diverse CNCE elements into a single unit capable of operating in the DCS environment.

To provide an objective frame of reference for evaluating the effectiveness of the CRF alternative relative to the other alternatives, DCEC directed that it be assumed that the CRF had been redesigned for operation in the DCS. It would be microprocessor-based, compatible with ATEC for interfacing and message exchange, remotely and locally controllable as is the DNC-B, and compatible with the DCS technical control with respect to power, size, reliability and maintainability. To accomplish this, a research and development cost equivalent to that required for the DNC-B has been assumed; uninstalled equipment cost for the CRF is given in Appendix A.

CRF application to the baseline system is directed only at automating the AUTOSEVOCOM II interface. Routing and deployment considerations are the same as for the DNC-B, Alternative 3. An important difference between the CRF and DNC-B which appeared during the study is the degree to which they utilize transmission capacity. The smallest transmission group interface for the CRF is 128 kb/s, compared with 64 kb/s for the DNC-B. As a result, the CRF only provides approximately 40 percent of the AUTOSEVOCOM II circuit mileage savings of Alternative 3. Overall, the CRF requires 3.5 percent fewer circuit miles than the baseline system.

The CRF/AUTOSEVOCOM II equipment summary is given in Table 3-6. Control of CRF hardware is examined in section 4.2.3.

TABLE 3-6. CRF/AUTOSEVOCOM II HARDWARE DEPLOYMENT SUMMARY

	EQUIPMENT QUANTITIES (3)								
			LGM-		SMA-				
Location	GM	LM	8	16	4	8	16	SIU	CRF
Hillingdon	1	22	0	0	0	0	0	0 0	1
Feldberg	1	13	0	0	0	0	0	0 0	1
Lankerkopf	1	49	0	0	0	0	0	0 0	1
Donnersberg	2	85	0	0	0	0	0	0 0	1
Digital Concentrators (1)	0	169	0	0	4	14	24	26 0	0
Other (2)	0	0	0	0	4	4	11	5 0	0
Total	5	338	0	0	8	18	35	31 0	4

Notes:

(1) 26 Digital Concentrator Locations

(2) Branching or Rechannelization Sites

(3) LM: Loop Modem

GM: Group Modem

LGM: Loop Group Multiplexer

SMA: Level A Submultiplexer

SIU: System Control Interface Unit

3.2.6 DNC-A, CRF Joint Deployment/Alternative 6

The joint deployment of DNC-A and CRF hardware in the baseline system realizes no additional cost or operational benefits over those achieved in the individual deployments. This differs from the joint deployment of DNC-A and DNC-B which interface directly at the T1 level, indirectly via the CEG, and complement one another functionally. The CRF and DNC-A have basically incompatible data rates and operate independently. The equipment requirements for Alternative 6 are given by the sum of the requirements for Alternatives 2 and 5. Control for Alternatives 6a and 6b is as specified in section 4.2.3.

3.2.7 Deployment Recommendations

Within each of the alternative deployments considered in this section, the hardware design and its allocation to stations in the

baseline were optimized to reduce equipment quantities, to reduce equipment costs and maximized cost benefits. Existing tradeoffs were identified and evaluated, and any required changes were implemented.

As a result of the deployment analyses, it became apparent that there exists the potential for extensive AUTOSEVOCOM II circuit mileage savings through the development of a 4-channel port card for the first level multiplexer. This card would be required to accept up to four 16-kb/s channels and to multiplex them for transmission in a single 64-kb/s PCM channel. The port card would use T1 framing for synchronization in order to avoid any transmission overhead.

If this submux port card does not significantly affect TD-1192 cost and reliability, its use would provide reductions in acquisition cost and operating and maintenance cost over the baseline system. To estimate the magnitude of the reduction requires knowledge of the life cycle cost sensitivity of the baseline system to circuit mileage and equipment changes. This information will be made available by the cost benefits analysis of section 4. The estimated life cycle cost impact of four channel port card is given in section 5.4.

3.2.8 Uninstalled Equipment Costs

Uninstalled costs for all equipments used in Alternatives 2 through 6 are listed in Appendix A. These are primary inputs to the cost benefits analysis of section 4. It should be noted that the DNC-B costs include the design modification specified in section 3.2.3.

SECTION 4

LIFE CYCLE COSTS/COST BENEFITS ANALYSIS

4.1 METHODOLOGY

The life cycle costs and related costs benefits associated with the five DNC alternatives will now be examined. The major inputs to this analysis are the results of Tasks 1 through 8 and the system descriptions generated in sections 2 and 3. The methodology employed is one in which the total life cycle cost associated with each alternative is divided into independent elements which are determined separately and then combined. The single element common to all alternatives is the life cycle cost associated with the baseline transmission equipment and personnel. This follows, since, as described in section 3, each DNC alternative is simply an augmentation to the DCS baseline system.

The overall costing process is illustrated in Table 4-1. As shown, six basic life cycle cost elements are defined; the total life cycle cost for an alternative is given by the summation of component elements and an adjustment to account for circuit mileage variations. The three operational factors shown in Table 4-1 are inputs to the baseline transmission element and are adjustments to the manning and equipment levels. These factors for an alternative are determined from all operational benefits associated with that alternative. Thus, the operational factors provide a direct means of estimating the monetary worth (cost benefit or cost penalty) of the various DNC operational benefits determined during the first eight tasks of the program.

The quantification of operational factors, circuit mileage adjustments, life cycle costs and performance is the subject of the remainder of section 4.

4.2 COST BENEFITS CONSIDERATIONS

DNC capabilities provide the potential for cost benefits in three general areas: manpower savings, hardware savings and circuit mileage savings. Manpower savings stem principally from the automation DNC brings to the technical control area. Examples are remote network

TABLE 4-1. COST BENEFITS METHODOLOGY

ALTERNATIVE		BASIC LCC ELEMENTS						OPERATIONAL FACTORS			CIRCUIT MILEAGE ADJUST.
		BASELINE TRAN. EQUIP. & PER.	MANUAL INTER. EQUIP.	DNC-A EQUIP.	DNC-B EQUIP.	DNC-A/DNC-B EQUIP.	CRF EQUIP.	MANPOWER ADJUST.	TRAN. EQUIP. ADJUST.	CONTROL EQUIP. & ATEC. INTER	
BASELINE	a	X	X								
	b	X	X					X			
DNC-A	a	X	X	X				X	X	X	
	b	X	X	X				X	X	X	
DNC-B	a	X			X			X	X	X	X
	b	X			X			X	X		X
DNC-A/ DNC-B	a	X				X		X	X	X	X
	b	X				X		X	X	X	X
CRF	a	X					X	X		X	X
	b	X					X	X			X
DNC-A/ CRF	a	X		X			X	X	X	X	X
	b	X		X			X	X	X	X	X

NOTE: a - NO ATEC DEPLOYMENT
b - WITH ATEC

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reconfiguration and circuit restoration. Hardware savings are due primarily to the elimination of rechannelization, and a more efficient AUTOSEVOCOM II interface. Circuit mileage savings are a result of the minimization of backhauling and the general positive impact of channel reassignment on transmission capacity utilization.

The translation of DNC capabilities into the operational factors shown in Table 4-1 is the purpose of this section. Section 4.3 determines whether the DNC provides any cost benefits based on the operational factors defined here.

4.2.1 Manning Analysis

The purpose of the manning analyses is to estimate the variation from the baseline manpower level (as specified in Table 2-1) associated with each DNC alternative. The variations arise from three sources: technical control automation due to ATEC, technical control automation due to DNC-A, and system equipment level changes which accompany every alternative and option. In general, automation results in a decrease in the number of technical controllers and maintenance personnel required; whereas, the net equipment change due to each alternative, with the exception of DNC-B, without ATEC results in an increase in maintenance personnel. The total baseline personnel change (operational factor) is given by the sum of the effects of automation and equipment level changes.

The impact of automation is estimated through a queueing analysis similar to that used in a "Manning Reduction by Automation of the Technical Control Function," Reference 11. The technical control facility is modeled by a M/M/k queueing system in steady state. The effect of DNC-A and ATEC is to increase service rates of technical controllers or to decrease the arrival rates of technical control operations, thereby providing a tradeoff between manning levels and queue length (or facility availability). Neither DNC-B nor the CRF when examined alone (without ATEC or DNC-A) provides sufficient automation in the technical control facility to play a role in the automation analysis.

The impact of equipment level changes on maintenance personnel is estimated by determining the net increase in maintenance workload, where workload is assumed to be proportional to the total MTTR (mean-time-to-repair) plus MTT (mean-travel-time) for all equipments in the network.

The actual manning analysis is divided into two phases. The first determines the variation in technical controllers for each alternative, and the second, the variation in maintenance personnel.

4.2.1.1 Technical Controller Analysis

In this section the technical control facility is modeled by a M/M/k queueing system and the impact of automation on technical control personnel is estimated. The analysis tools used here are identical to those used in Reference 11 and will not be discussed. However, the overall scope and purpose of this analysis is considerably different, and it is these differences and the results of these differences that will be discussed. All assumptions will be clearly identified to simplify future work in this area. In addition, certain assumptions might be considered somewhat arbitrary by the reader. However, as pointed out in Reference 11, all major assumptions are either consistent with technical control practices or simplify the analysis and do not introduce significant error.

Many of the inputs to this analysis are also from Computer Science Corporation's time and motion study performed at Croughton and Hillingdon (Reference 12). Since the results obtained are consistent among themselves and with certain conclusions in Reference 12, a high degree of confidence can be placed in the modeling technique.

The procedure followed in the analysis is to first model the technical control facility and calibrate the model; next, to determine the impact of automation on model parameters; and finally to exercise the model for the various set of parameters defined. These three steps are performed below.

4.2.1.1.1 <u>Technical Control Modeling</u> - The technical control modeling assumed here is consistent with Reference 11 and will only be discussed in sufficient detail to permit easy comprehension of subsequent results. Justification of the model and a thorough description of the source data used here may be obtained in Reference 11.

Technical control operations can be conveniently grouped into three categories:

a. Responses to deterministic arrivals such as performance monitoring, trending (with respect to ATEC) and reporting (periodic and Raday reports).

b. Responses to random arrivals such as circuit failures, assistance to other facilities, and near-real-time (NRT) reporting.

c. Idle or standby time.

The actual modeling is performed only for the technical control action in response to random arrivals. The technical control facility (TCF) is assumed to be a multiserver queueing system with three sources of arrivals requiring three types of technical controller service actions:

a. Circuit restoration and fault clearing
b. Assistance to other TCFs
c. NRT reporting.

An important output of the model is the average technical controller standby time available. Implicitly assumed in the modeling is that the technical control schedules the servicing of deterministic arrivals during standby time. Thus, the model calibration must be such to provide sufficient standby time to service deterministic arrivals.

Within this framework, the basic modeling assumptions are as follows:

a. Interarrival times are exponentially distributed

b. Service times are exponentially distributed

c. Service is on a first-in, first-out basis

d. Servers are characterized by a mean service time with an exponential distribution.

The basic analysis assumptions are as follows:

a. The system is in steady state with an infinite source population and an infinite queue available.

b. Impact of technical control automation is to alter the technical control service times and/or arrival rates.

c. Source data is based on References 11 and 12.

d. An average technical controller shift is assumed. Three shifts with different arrival rates are not considered.

e. The basic equations governing the model are shown in Appendix B and are based on Reference 13.

The figure of merit used in the analysis is the expected technical control facility availability, E(N). It is given by

$$E(N) = \frac{\text{Total Circuits - (Expected Number of Inoperative Circuits in Queue)}}{\text{Total Circuits}}$$

and represents the average fraction of circuits at a station or TCF which are available at a given instant in time.

4.2.1.1.2 Model Calibration - Source data for model calibration is based on measurements made at Croughton, England, as discussed in Reference 11. The resulting model inputs obtained are as follows:

a. Distribution parameters for random arrivals

1. Circuit outages - Poisson parameter $\lambda_1 = 1.1\ hr^{-1}$

2. Assistance to other facilities - Poisson parameter $\lambda_2 = 13.44\ hr^{-1}$

3. NRT reports - Poisson parameter $\lambda_3 = 2.6\ hr^{-1}$

b. Distribution parameters for service times of random arrivals

1. Circuit outages - exponential parameter $\mu_1 = 0.43\ hr^{-1}$

2. Assistance to other facilities - exponential parameter $\mu_2 = 5.4615\ hr^{-1}$

3. NRT reports - exponential parameter $\mu_3 = 13.7\ hr^{-1}$

The above data is based on a TCF that handles approximately 800 long-haul circuits. Direct application of this data to the 20 TCFs identified in the baseline system is not possible since none of these TCFs has exactly 800 circuits. The analysis approach used was to divide the baseline system into classes of sizes and to analyze each class separately by assuming that the arrival rates for each class are scaled (relative to Croughton's) in proportion to the ratio of long-haul circuits. It is assumed that service rates are the same. Examination of Table 2-1 reveals that the 20 TCFs in the baseline can be conveniently divided into three classes as shown in Table 4-2.

TABLE 4-2. TCF CLASSES

CLASSES	NO. STATIONS	AVE. NO. OF TECH. CONTROLLERS	AVE. NO. OF MAINT. PERSONNEL
AUTOVON Stations	6	16	14
Large* (>300 circuits)	7	7	8
Small (≤300 circuits)	7	12	13

*Excludes AUTOVON stations

Application of the source data above to the three classes of TCF in accordance with the queueing formulation of Appendix B yields the results shown in Table 4-3.

TABLE 4-3. MODEL CALIBRATION

TCF CLASS	STANDBY TIME PER TECH. CONTROLLER	FIGURE OF MERIT E(N)
AUTOVON	0.39	0.99956
Large	0.37	0.99952
Small	0.62	0.99955

It should be noted that the standby time obtained during model calibration is more than sufficient to handle deterministic arrivals based

on the rates specified in Reference 11. Additionally the standby times obtained are consistent with the 0.5 obtained by a time and motion study (Reference 12). Another interesting and intuitively appealing result is that the figure of merits obtained for the three classes of TCFs are in close agreement. This indicates that manning levels determined in section 2.1 if not absolutely correct are at the very least consistent since they provide approximately the same grade of service for TCFs with widely different manning requirements.

Another result to be obtained in this section is the contribution of the TD-1192 and FRC-163 to the DCS reference circuit unavailability. This information is employed in the next section to estimate the impact of ATEC and DNC automation. The source data used here is obtained from Reference 14. In this document an extensive fault-tree analysis is performed in order to determine circuit availability for DEB transmission equipment, which is used in the DCS baseline system of Alternative 1. Applying the results in Reference 14 to the reference circuit yields the data shown in Table 4-4. The column showing unavailability with ATEC assumes a capability for automated monitoring, fault isolation, reporting and remote switching of redundant equipment. This capability is provided by a device denoted as Transmission System Controller in Reference 14. Assumed here is that the future ATEC will provide at least these functions. Based on Table 4-4, the unavailability contribution by the TD-1192 is 6.6 percent with ATEC and 13.5 percent without ATEC. The unavailability contribution by the FRC-163 is 79.6 percent with ATEC and 78 percent without ATEC. The unavailability contribution of the path has been ignored in this analysis. Subsequent results will assume the unavailability data of Table 4-4 is contributed to equally by all failures. Although this assumption is not consistent with the derivation of Table 4-4, lack of failure data for the future DRAMA equipment and the consideration that the assumption will not significantly distort the results force this decision.

The final information required prior to determination of the impact of technical control automation is the contribution of the local

TABLE 4-4. DCS REFERENCE CIRCUIT EQUIPMENT UNAVAILABILITY BREAKDOWN*

EQUIPMENT	QUANTITY	UNAVAILABILITY WITHOUT ATEC	UNAVAILABILITY WITH ATEC
TD-1192	2	8.72×10^{-5}	8.72×10^{-5}
TD-1193	10	1.77×10^{-5}	1.1×10^{-5}
FRC-163-Manned	10	8.23×10^{-5}	6.34×10^{-5}
-Unmanned	20	9.68×10^{-4}	4.4×10^{-4}
KG-81	10	1.65×10^{-4}	4.37×10^{-5}
Total		1.32×10^{-3}	6.45×10^{-4}

*Excludes Path

loop to circuit failures. According to Reference 12, the local loop accounts for 10 percent of all circuit failures.

4.2.1.1.3 Impact of Automation on Technical Control Model - First, the impact ATEC on the technical control model will be determined, then the impact of DNC-A, and finally the impact of the joint deployment of ATEC and DNC-A.

Figure 4-1 illustrates the definition of the circuit restoration and fault clearing actions of the technical controller specified in section 4.2.1.1.1. This definition is a composite of data in References 11 and 12 and discussions with DCEC personnel. As shown in Figure 4-1, the technical controller spends an average of 139 minutes on each circuit restoration and fault clearing action. At the end of that time, the circuit has been restored (by equipment repair or rerouting), or no further action is fruitful and the technical controller goes to service the next arrival. Of the 139 minutes, the cumulative action time for the technical controller is approximately 20 minutes, where action time denotes the physical operations of patching, testing and coordination as defined in Reference 12. Not included in the 20 minutes, however, is any time required to prepare for these actions or time required to simply think the problem out. Obviously, no technical controller operates on pure reflexes.

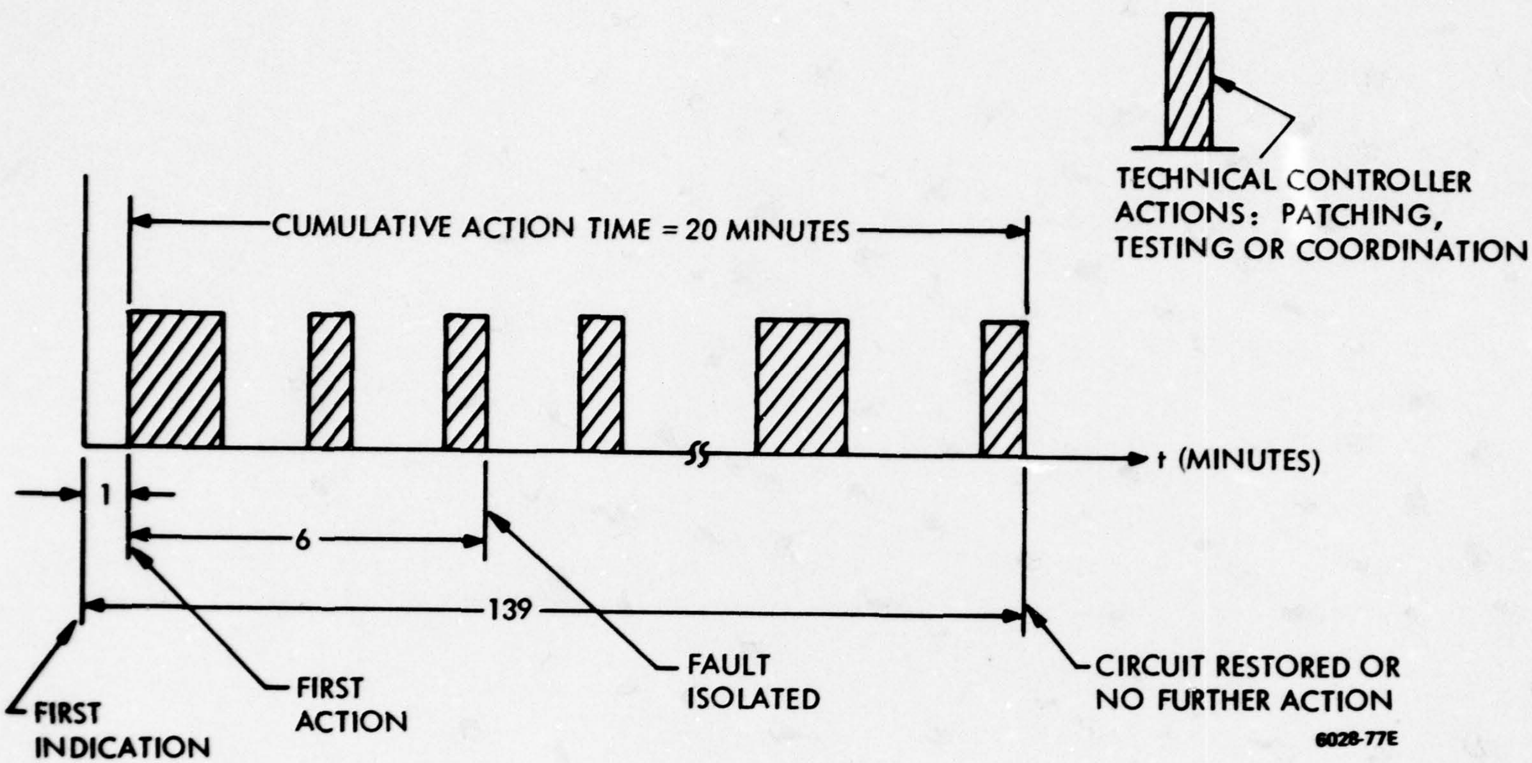

Figure 4-1. Description of Circuit Restoration and Fault Clearing Action

Based on the capabilities of ATEC as presently planned, it can be concluded that ATEC will reduce the total service time shown in Figure 4-1 by anywhere from 7 to 20 minutes. The 7 minutes follow since ATEC is to automatically isolate faults, and the 20 minutes follow since ATEC is to aid in testing and coordination and can be expected to eliminate the physical actions if not the preparation for them.

Trending is another benefit to be derived from ATEC. Trending will operate by detecting an out-of-tolerance condition before it becomes a failure. Thus, the out-of-tolerance condition would be picked up as a preventive maintenance action and not a technical controller action. This would result in a reduction in the arrival rates of circuit restoration and fault clearing actions. Based on results in Reference 15, it can be expected that ATEC will trend 10 to 20 percent of all radio failures. Using results in the previous section, radio failure accounts for approximately 72 percent (with and without ATEC) of all circuit failures; thus, ATEC can provide a decrease of between 7 and 14 percent in circuit outage arrival rates.

The role played by ATEC in reducing the service time for assisting other facilities is determined from data in Reference 12. Assuming that this assistance is for failures that occur at other TCFs, according to Reference 12, 40 percent of this time is consumed with testing, 4 percent with patching, and 49 percent with reporting. If it is conservatively assumed that ATEC only eliminate testing, service time is decreased by 40 percent.

There was no source data available upon which to accurately predict the impact ATEC would have on the service times associated with NRT reporting. However, because of the potential to provide automatic

a. Form storage and retrieval
b. Entry of stored data and parameters
c. Transmission (with ARQ) to appropriate DCS elements.

it was arbitrarily assumed that ATEC would reduce the service times associated with NRT reporting by 60 percent. This is the same value specified in Reference 11 as being indicative of the impact of automation on reporting.

A summary of the impact of ATEC on the arrival rates and service rates for the technical control model are given in Table 4-5.

A determination of the influence of DNC-A on the technical control model proceeds along similar lines to that use for ATEC alone. Recalling the capabilities provided by DNC-A as described in section 3.2.2, any circuit can be rerouted except where there are failures in the first level multiplexer or local loops, or a node is isolated preventing the reroute. Based on Figure 4-1 and Reference 16, the average time to isolate a circuit failure is 7 minutes without ATEC and 2 minutes with ATEC. Assuming that the time to coordinate a reroute via DNC-A is 5 minutes without ATEC (technical controller enters reroute data into DNC control network; see section 4.2.3) and 1 minute with ATEC (ATEC dynamically calculates reroute or uses stored plans), then neglecting node isolations the service time for circuit restoration is reduced from 78 percent without ATEC to 83 percent with ATEC. This follows, since, based on Table 4-4, the first level multiplexer and local loop account for only 16 percent of all failures without ATEC and 22 percent with ATEC.

To account for node isolation, it is pessimistically assumed that the number of circuits eligible for rerouting decreases by 75 percent. Thus, only 21 percent of the failed circuits can be restored by rerouting without ATEC and 20 percent with ATEC. The net service time reduction when node isolations are considered is 20 percent without ATEC and 21 percent with ATEC. The two cases, including and excluding node isolations, are used to bound the impact of DNC-A on circuit restoration and fault clearing.

As with the ATEC alone case, the influence of DNC on service time associated with assistance to other facilities can be determined from Reference 12. Since all manual patching actions for testing can be eliminated by DNC in this case, and assuming that DNC-A can automate 15 percent of all related testing actions (end-to-end or loopback BER measurements), DNC-A can reduce the service times for assistance to other facilities by 4 percent (condidering patching alone) to 10

TABLE 4-5. IMPACT OF AUTOMATION ON TECHNICAL CONTROL MODEL SUMMARY

OPERATION	ATEC		DNC-A	ATEC+ DNC-A	
	ARRIVAL RATE	SERVICE TIME	SERVICE TIME	ARRIVAL RATE	SERVICE TIME
CIRCUIT RESTORATION AND FAULT CLEARING	7-14%	5-15%	20-80%	7-14%	20-80%
ASSISTANCE TO OTHER FACILITIES	0	40%	4-10%	0	44%
NRT REPORTING	0	60%	0	0	60%

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percent (considering patching and testing) without ATEC and from 40 to 44 percent with ATEC. Assumed in the latter case is that DNC-A does not provide any testing benefits which are not derived from ATEC.

Table 4-5 summarizes the impact on the technical control model of DNC-A with and without ATEC.

4.2.1.1.4 Technical Control Personnel Adjustments - The results of the previous section are used here to calculate the reduction in technical controller manpower brought about by automation. The data in Table 4-5 is applied to the three classes of TCFs defined in section 4.2.1.1.2 for each alternative, and for two cases. Case 1 is defined by the set of maximum reductions in Table 4-5 and Case 2 by the set of minimum reductions. The purpose of evaluating the two cases is two-fold. First, they serve to bound the results to be expected from automation. Recalling the way in which they were derived, Case 1 includes mostly optimistic assumptions, whereas, Case 2 includes mostly pessimistic assumptions. Second, the two cases provide a means of determining the sensitivity of the life cycle cost results to manpower adjustments. This in turn yields a quick and conveniently way to estimate system changes.

Evaluating the technical controller manpower reduction involves determining the tradeoff between technical controllers and figure of merit for each class of station for each case. Figure 4-2 shows the tradeoff for the AUTOVON class of stations for Case 1. The three curves shown are for the three types of automation examined, ATEC only, DNC-A only and joint deployment of ATEC and DNC-A. For each type of automation, as the number of technical controllers increases the figure of merit increases until the point where the queues are reduced to essentially zero. The horizontal line in Figure 4-2 represents the baseline figure of merit, E(N), obtained during model calibration.

The method used to obtain the permitted technical controller reduction is simply to reduce the number of technical controllers for each type of automation until E(N) is no less than ten percent above

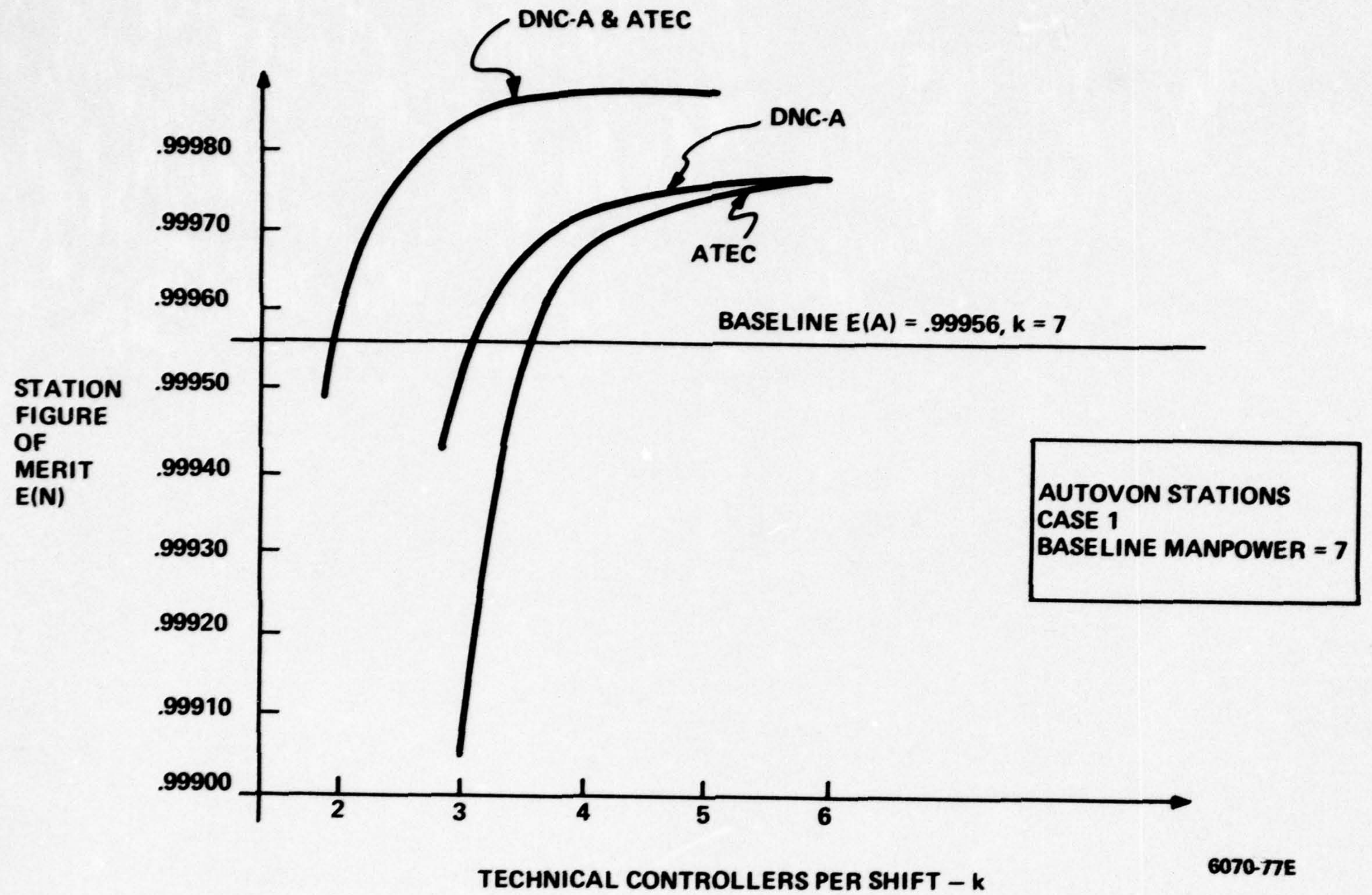

Figure 4-2. Technical Control Manpower - Station Availability Tradeoff

baseline. The ten percent figure is arbitrary and is felt to be indicative of the increased performance required for a new system. For the example being considered, the technical controllers can be reduced from 7 to 4 for both ATEC and DNC-A, and to 2 for joint deployment of ATEC and DNC-A.

Performing the above analysis for all alternatives and case results in the technical controller manpower reduction summary shown in Table 4-6. It may be recalled that the total number of technical controllers in the baseline system is 232.

4.2.1.2 Maintenance Manpower Analysis

The maintenance manpower level in the baseline system is 489. Of these, 266 are located at stations with technical controllers assigned and 223 are located at stations with no technical controllers. At stations where maintenance personnel and technical controllers are collocated, maintenance personnel perform maintenance functions only. However, at stations where there are no technical controllers, maintenance personnel perform both the maintenance and technical control functions.

Based on discussions with DCEC personnel, it is assumed that (1) at technical control facilities the maintenance workload splits evenly between preventive and corrective maintenance, and (2) at the remaining manned locations, 25 percent is allotted for technical control type actions, and 37.5 percent each for corrective and preventive maintenance. Summarizing, in the baseline system, the maintenance workload breaks down as follows:

a. Preventive Maintenance - 217 men
b. Corrective Maintenance - 216 men
c. Technical Control functions - 56 men.

The impact of automation on preventive maintenance actions is to decrease time for testing but to increase the amount of testing to be done because of the addition of the automation equipment. Since ATEC and DNC-A are not specifically aimed at reducing the preventive maintenance testing and because the quantity of automation equipment is

TABLE 4-6. TECHNICAL CONTROL PERSONNEL ADJUSTMENT SUMMARY

ALTERNATIVE		CASE 1	CASE 2
BASELINE	a	0	0
	b	-78	-46
DNC-A	a	-78	- 6
	b	-143	-78
DNC-B	a	0	0
	b	-78	-46
DNC-A&	a	-78	- 6
DNC-B	b	-143	-78
CRF	a	0	0
	b	-78	-46
DNC-A	a	-78	- 6
&CRF	b	-143	-78

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CASE 1: MAXIMUM MANPOWER REDUCTION
CASE 2: MINIMUM MANPOWER REDUCTION
a. WITHOUT ATEC
b. WITH ATEC

negligible compared to the total baseline equipment, it is confidently assumed that neither ATEC nor DNC-A will significantly impact this area. Thus preventive maintenance manpower is assumed to be unchanged by the introduction of automation.

The impact of automation on corrective maintenance is to increase the manpower levels required because of the increase in the number of failures occurring in the network over a given period of time. The number of failures in this case is not negligible because of the complexity of the automation equipment. The way in which the increase was determined was to calculate the total man-hours required for corrective maintenance for each alternative and then to vary manning from the baseline in direct proportion to changes in man-hours. Total man-hours are calculated by adding the following:

a. For each equipment type, the product of MTTR, total failures per year and total equipment quantity

b. For each unmanned station, the product of 2.5 hours and total failures per year for that station.

The first factor accounts for direct labor in repairing equipment and the second factor accounts for travel time (MTT = 2.5 hours) to unmanned stations. The total man-hours required for each alternative are shown in Table 4-7. The translation of this data into manpower changes is shown in Table 4-8. The MTBFs and MTTR used in the calculations are shown in Table 4-9. MTBF and MTTR which have an asterisk are estimated, and all others are based on equipment specifications. It should be noted from Table 4-8 that only the DNC-B and CRF alternatives (without ATEC) do not increase the corrective maintenance workload. This is due to the large amount of equipment they replace when used to interface AUTOSEVOCOM II.

The effect of ATEC and DNC-A on those maintenance personnel performing technical control functions is expected to be the same as that on technical control personnel. Accordingly, the results of section 4.2.1.1 are applied by using the same percentage decreases obtained for the small class of TCFs. The resulting manpower adjustments are shown in Table 4-10.

TABLE 4-7. CORRECTIVE MAINTENANCE MAN-HOUR REQUIREMENTS

ALTERNATIVE	WITHOUT ATEC	WITH ATEC
1. Baseline	3546	3937
2. DNC-A	3857	4216
3. DNC-B	3499	3886
4. DNC-A and DNC-B	3799	4154
5. CRF	3557	3943
6. DNC-A and CRF	3814	4174

TABLE 4-8. CORRECTIVE MAINTENANCE MANPOWER ADJUSTMENTS

ALTERNATIVE	WITHOUT ATEC	WITH ATEC
1. Baseline	0	+23
2. DNC-A	+19	+41
3. DNC-B	-2	+20
4. DNC-A and DNC-B	+15	+37
5. CRF	0	+24
6. DNC-A and CRF	+16	+38

TABLE 4-9. EQUIPMENT RELIABILITY AND MAINTAINABILITY

EQUIPMENT	MTBF[1]	MTTR[1]	EQUIPMENT	MTBF[1]	MTTR[1]
TD-1192	3500	.167	ATEC Sector	500	.25
TD-1193	1600	.25	ATEC Node	500	.25
FRC-163	1600	.5	ATEC Station small[2]	2100	.25
KG-81	10000	.5	ATEC Station Medium[2]	700	.225
LM	6000	.25	ATEC Station Large[2]	350	.20
GM	5000	.25	DNC Control-CPU	5000*	.25*
TGM	5000*	.5*	DNC Control-TTY	5000*	.25*
LGM	3000	.5	DNC Control-VDU	5000*	.25*
SMA	5000*	.15*	DNC Control-Disk	5000*	.25*
SIU	5000*	.15*	DNC Control-MUX	5000*	.25*
DNC-A/32	1071	.5	DNC Control-CRF	5000*	.25*
DNC-A/64	619	.5			
DNC-A/96	422	.5	[1]Units of 1/Hr		
DNC-A/128	327	.5			
DNC-B/6	927	.5	[2]DCEC Supplied		
DNC-B/12	684	.5			
DNC-B/18	497	.5			
CEG	2275	.25			
CRF[2]	410	.5			

TABLE 4-10. MAINTENANCE MANPOWER ADJUSTMENTS DUE TO AUTOMATION OF TECHNICAL CONTROL FUNCTIONS

ALTERNATIVE		CASE 1	CASE 2
Baseline	a	0	0
	b	-14	-14
DNC-A	a	-14	0
	b	-28	-14
DNC-B	a	0	0
	b	-14	-14
DNC-A and DNC-B	a	-14	0
	b	-28	-14
CRF	a	0	0
	b	-14	-14
DNC-A and CRF	a	-14	0
	b	-28	-14

a: Without ATEC

b: With ATEC

Case 1: Maximum Manpower Reduction

Case 2: Minimum Manpower Reduction

4.2.1.3 Manning Analysis Summary

Within section 4.2.1, the manpower adjustments attendant with each alternative to the DCS baseline system have been computed. Manpower adjustments derive from three sources: automation in the technical control facility, increases in the amount of corrective maintenance to be performed, and automation of technical control functions performed by maintenance personnel at locations with no TCFs. The specific manpower adjustment associated with each source is given in Tables 4-6, 4-8 and 4-10, respectively. Table 4-11 shows the total manpower adjustment due to all sources. Case 1 denotes that the results represent an optimistic

view of the impact of automation on technical control functions, and Case 2 denotes a more pessimistic view. TAble 4-11 is a direct input to the life cycle cost model and is the first of the three operational factors shown in Table 4-1.

TABLE 4-11. TOTAL DCS BASELINE PERSONNEL ADJUSTMENTS

ALTERNATIVE		CASE 1	CASE 2
Baseline	a	0	0
	b	-69	-37
DNC-A	a	-73	+13
	b	-130	-51
DNC-B	a	-2	-2
	b	-73	-40
DNC-A and DNC-B	a	-77	+9
	b	-134	-55
CRF	a	0	0
	b	-68	-36
DNC-A and CRF	a	-76	+10
	b	-133	-54

a: Without ATEC

b: With ATEC

Case 1: Maximum Manpower Reduction

Case 2: Minimum Manpower Reduction

4.2.2 Equipment Savings

The deployment of DNC-A provides network flexibility exceeding that available in the baseline digital hierarchy. This added flexibility derives from the channel reassignment function which permits access to any or all channels at a DNC-A equipped site. In general,

the channel reassignment approach requires breakout only for terminating channels and thereby eliminates having to drop all channels in a group in order to access part of the group. The practice of dropping part of a group and through-connecting the remainder of the group is denoted rechannelization. Refer to Reference 1, section 3.2.3, for a more detailed explanation of rechannelization. Based on the planned DEB group routing and the deployment of DNC-A specified in section 3.2.2, it was determined that 26 first level multiplexers could be eliminated. The possibility of second level multiplexer savings due to the elimination of the first multiplexers was not investigated because of the lack of circuit routing information. However, this quantity is indirectly accounted for by circuit mileage considerations in section 5.2.

Another source of equipment savings is the DNC-B and CRF AUTOSEVOCOM II interfaces. The 16-kb/s channel reassignment capability of these devices permits a more efficient utilization of the transmission backbone by requiring fewer overhead and unused channels. Not only does this reduce network channel mileage but it also eliminates the first level multiplexers required in the baseline system to accommodate the overhead and unused channels. The multiplexer savings determined in this case are shown in Table 4-12, along with those due to rechannelization. As a frame of reference, the total number of first level multiplexers in the baseline system is 597. The totals in Table 4-12 are direct inputs to the life cycle cost model and represent the second of the three operational factors shown in Table 4-1.

4.2.3 Control Equipment ATEC Interface

Each of the six study alternatives is evaluated for two options: one which does not include a deployment of ATEC equipment and another which does. The cost impact of the two options is examined below.

As discussed in Reference 1, section 6.2.2, control of DNC hardware is provided by a hierarchical structure which is physically integrated into the planned system control subsystem; also, operational control of the hardware is distributed between the CEG and software

TABLE 4-12. TRANSMISSION EQUIPMENT ADJUSTMENT SUMMARY

ALTERNATIVE		TD-1192's SAVED		TOTAL
		RECHANNELIZATION	AUTOSEVOCOM II INTERFACE	
BASELINE	a	-	-	
	b	-	-	
DNC-A	a	26	-	26
	b	26	-	26
DNC-B	a	0	5	5
	b	0	5	5
DNC-A &	a	26	8	34
DNC-B	b	26	8	34
CRF	a	0	0	0
	b	0	0	0
DNC-A &	a	26	0	26
CRF	b	26	0	26

a: WITHOUT ATEC
b: WITH ATEC

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located at the ATEC nodal level. Thus, when ATEC is deployed, the only additional control costs incurred are those required to interface the DNC hardware with ATEC. When ATEC is not deployed, the cost of an overall control network must be incurred. The actual interfaces assumed for the two options are shown in Figure 4-3.

With respect to the ATEC option, DNC has been designed to interface directly with the ATEC CIS, therefore no costs are incurred at stations receiving both ATEC and DNC equipment. At stations where there is DNC hardware but no ATEC deployment (refer to section 2.1.3 for details of ATEC deployment), an I/O terminal for the technical controller or maintenance person is required. Further, it is assumed that DNC hardware can interface the station orderwire without any additional costs. Although the telemetry interface is shown as 150 b/s, DNC has a programmable interface which operates at rates up to 9600 b/s and will be adjusted to individual station requirements.

For the without-ATEC option as shown in Figure 4-3, each station receiving DNC hardware is equipped with an I/O terminal. In addition, for the DNC-A alternatives, a network controller processor system is deployed at those stations which are ATEC nodes in the ATEC option. This system supplies the processing, storage, and I/O capabilities required to support digital network control at up to 16 locations and in accordance with control requirements established in Reference 1. For the DNC-B and CRF alternatives, only a single network controller processor system is required since only four locations are involved.

Based on the uninstalled equipment costs given in Appendix A, the total cost for control equipment/ATEC interface in each alternative is given in Table 4-13. Assumed in these figures is that all telemetry channels required for control of DNC and CRF hardware are cost-free. This is the last operational factor specified in Table 4-1. Note that this operation factor is, in fact, a cost penalty and not a cost benefit as are the other two factors. Also included in Table 4-13 are the uninstalled equipment costs for ATEC. These are inputs to the life cycle cost analysis and were provided by DCEC.

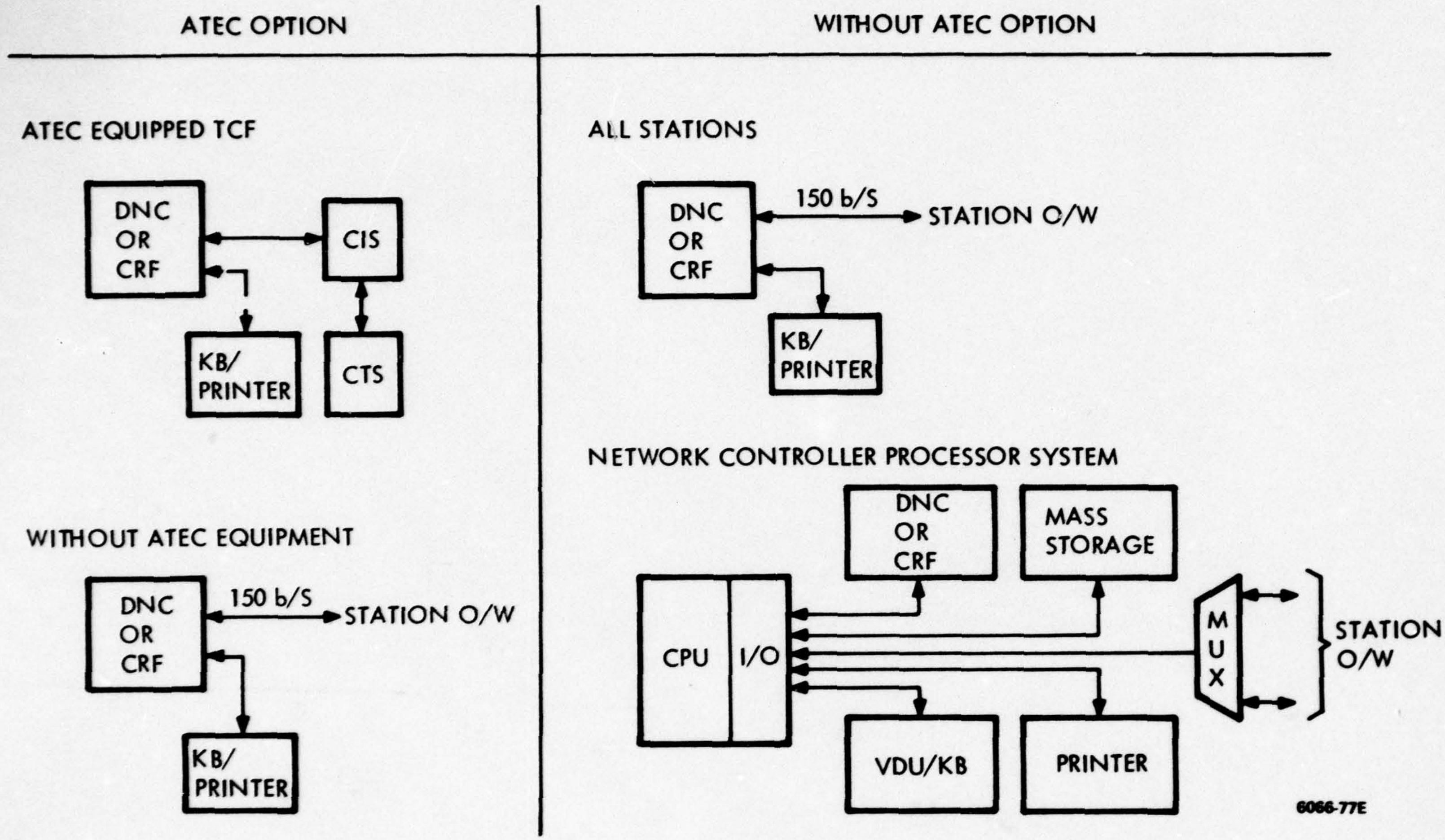

Figure 4-3. Control Equipment and ATEC Interface

TABLE 4-13. CONTROL EQUIPMENT/ATEC INTERFACE UNINSTALLED HARDWARE COSTS

ALTERNATIVE		CONTROL EQUIPMENT/ ATEC INTERFACE ($000)	ATEC HARDWARE ($000)
BASELINE	a	0	0
	b	0	6260
DNC-A	a	341	0
	b	65	6260
DNC-B	a	34	0
	b	0	6260
DNC-A	a	341	0
&DNC-B	b	65	6260
CRF	a	34	0
	b	0	6260
DNC-A	a	361	0
& CRF	b	85	6260

a: WITHOUT ATEC
b: WITH ATEC

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4.2.4 Circuit Mileage Savings

All three channel reassignment devices, DNC-A, DNC-B and the CRF, provide the potential to reduce channel mileage over that required in the baseline. DNC-A realizes this potential through the elimination of backhauling (see Reference 1, section 3.2.1); both DNC-B and the CRF achieve reduced circuit mileage through a more efficient AUTOSEVOCOM II interface.

The specifics of the DNC-B and CRF AUTOSEVOCOM II interfaces and their related circuit mileage savings are discussed in sections 3.2.3 through 3.2.6. Table 4-14 summarizes the results described there. Since the DNC-A alternative uses the same AUTOSEVOCOM II interface as that used in the baseline system, there are no AUTOSEVOCOM II mileage savings associated with it.

The impact of DNC-A on backhauling in the DEB system could not be determined because of the unavailability of channel routing information at this point in time. When this routing becomes available, however, it is unlikely that backhauling will be a significant factor because the network will be in the early stages of development and most direct routes will not have been filled. In order to get an indication of the role backhauling might play in the latter stages of DEB development (e.g., post-1990 era), it was decided to investigate the role backhauling plays in the present analog DCS (European theater only), a mature network.

Two types of backhauling can be identified, both of which can be minimized, if not eliminated, by the capability to reassign channels between through-groups (as provided by DNC-A). One type simply involves circuitous channel routing through the network and the other a double routing through a node. Channel routing information available at DCEC showed no indication of the second type of backhauling in the present European DCS. Information to determine the extent of the first type was not available. Based on these results, backhauling is not directly considered in the cost benefits analysis, although it is expected that backhauling of the first type will be a problem in the later stages of DEB. Consequently, the impact of backhauling on life cycle cost is investigated in section 5.3.

TABLE 4-14. AUTOSEVOCOM II CIRCUIT MILE SAVINGS

ALTERNATIVE		TOTAL CIRCUIT MILES	PERCENT SAVINGS
BASELINE	a	83,533	—
	b	83,533	
DNC-A	a	83,533	—
	b	83,533	
DNC-B	a	76,565	8.1
	b	76,565	
DNC-A	a	73,197	12.4
&DNC-B	b	73,197	
CRF	a	80,601	3.5
	b	80,601	
DNC-A	a	80,601	3.5
CRF	b	80,601	

a: WITHOUT ATEC
b: WITH ATEC

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As discussed in section 4.1, circuit mileage savings realized in an alternative are not an input to the life cycle cost analysis. Instead, they are accounted for by an adjustment to life cycle cost outputs. Based on direction from DCEC, circuit mileage savings are to be considered an equivalent reduction in multiplexer acquisition and associated operating and maintenance costs. Thus, circuit mileage savings will be accounted for by adjusting the total acquisition and operating and maintenance cost outputs by the appropriate reduction factors associated with the multiplexers as determined using the sensitivity results.

4.3 LIFE CYCLE COST ANALYSIS

One management decision tool useful in the evaluation of alternative system design approaches to the DCS baseline system is life cycle cost modeling and analysis. This technique is used to compute the total cost associated with research and development (R&D), acquisition, operation, and support of a system design over an extended life period for the purpose of determining the lowest overall cost alternative. When combined with measures of system effectiveness, life cycle cost values are used to select the optimum design and implementation approach.

4.3.1 Life Cycle Cost Model and Data

A life cycle cost model that is so structured to adapt easily to 12 system configurations (six alternatives with two options each) has been developed. In preparation of the model, the DCA Cost and Planning Factors Manual, Reference 10, was used in structuring three major cost categories:

a. Research and Development
b. Acquisition
c. Operating and Maintenance.

The research and development category covers all costs incurred during the concept initiation, validation and full-scale development phases of the program. These include cost of feasibility studies, engineering design, development fabrication, assembly and test of

engineering prototype models, initial system evaluation, and associated documentation. The costs in this category terminate with the satisfactory completion of testing. Acquisition costs refer to those program costs required beyond the development phase to introduce into operational use a new capability, to procure initial, additional or replacement equipment for operational forces, or to provide for major modifications at an existing capability. Operating and support costs include the costs of personnel, material, facilities, and other direct and indirect costs required to operate, maintain, and support the equipment/system during the operational phase. It includes the cost of all parts consumed in maintenance of the equipment as well as the costs of maintaining the necessary supply systems for parts, components, equipment and information.

A system description for six study alternatives was identified in sections 2, 3 and 4. This includes a system baseline which contains existing or proposed government equipment and alternative configurations containing additional equipment (e.g., DNC-A, DNC-B, and CRF) in various deployments and quantities. Existing equipment cost factors are GFI; DNC and related equipment costs are as described in Appendix A. GFI (Reference 2 through 10) was used extensively in determining equipment planning, cost, deployment, and maintenance requirements in the post 1984 time frame. Using this information in conjunction with GTE Sylvania data, the three cost categories were determined by a building block approach applied with DCA cost factors (Reference 10). The building block approach sub-divides the major cost categories to minimize errors in cost estimating and also allows direct changes when input data is updated.

4.3.1.1 Research and Development (R&D)

The research and development category covers all costs incurred during the concept initiation, validation and full-scale development phases of the program. R&D cost estimates for DNC equipment were obtained from GTE Sylvania information addressing the following cost categories:

a. Program Management
b. Engineering (Hardware and Software)
c. Fabrication
d. Development Tests
e. Test Support
f. Producibility Engineering and Planning
g. Peculiar Support and Test Equipment
h. Fee
i. General and Administrative
j. Other.

These costs would be incurred over a five-year period (1978-82) based on scheduling tailored to meet the DEB and AUTOSEVOCOM II programs.

4.3.1.2 Acquisition

Acquisition costs refer to those program costs required beyond the development phase to introduce into operational use a new capability, to procure initial, additional or replacement equipment for operational forces, or to provide for major modifications to an existing capability.

The procurement/acquisition cost category is broken into the cost elements shown in Figure 4-4. Prime mission equipment (PME) cost and quantity were obtained from GFI and GTE Sylvania estimates (Appendix A) and were used to determine many of the following cost elements:

a. Prime Mission Equipment (PME) - Cost and quantity of purchased equipment (GFI and GTE Sylvania)

b. Integration and Assembly - Efforts regarding technical and functional activities associated with design, development, parts, etc., into an installed, operational system (5 percent X PME)

c. Support and Test Equipment - Equipment required to test and calibrate PME

    1. Test and Common Equipment (10 percent X PME)
    2. Peculiar Support Equipment (5 percent X PME)

d. System Test and Evaluation - Validation of Engineering data on performance and all design associated efforts (5 percent X PME)

e. System/Project Management - Contractually performed system engineering and project management support

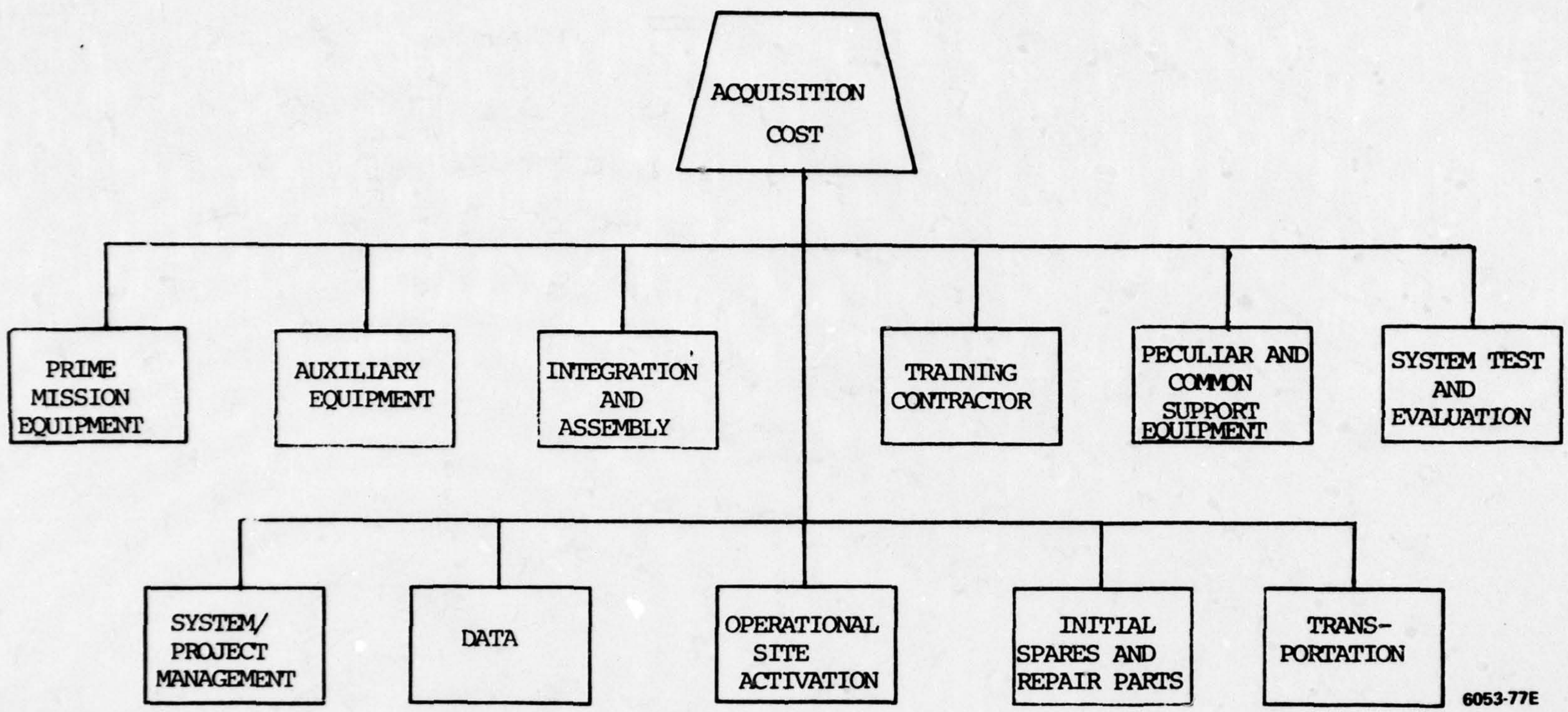

Figure 4-4. Procurement/Acquisition Costs-Building Block Concept

1. System Engineering - System definition, design R/M/S testing, etc. (10 percent X PME)

2. Project Management - Configuration, data, contract cost and schedule, QA, etc. (10 percent X PME)

f. Data - Technical data requirements (DD-1423) - ILS, technical publications, test, etc.

(Full level of support - new procurement) 9 X unit quantity (PME)

g. Operational Site Activation -

1. Contractor Technical Support (7 percent X (PME+STE))

2. Assembly, Installation and Checkout (40 percent X (PME+STE))

h. Initial Spares and Repair Parts -

1. Piece Parts (20 percent)
2. Modules (80 percent)

i. Transportation

1. Electronic Equipment (10 percent X (PME+STE))
2. Spares (9 percent X (Initial Spares))

The acquisition cost for the various alternatives and options contains each of the cost elements mentioned.

4.3.1.3 Operating and Maintenance (O&M)

Operating and maintenance costs include personnel, material, facilities, and other direct and indirect costs required to operate, maintain, and support the equipment/system during the operational phase. It includes the cost of all parts consumed in maintenance of the equipment as well as the costs of maintaining the necessary supply systems for parts, components, equipment and information. The O&M total cost consists of cost elements shown in Figure 4-5. The cost factors used to determine these cost elements are shown below:

a. Military Personnel - Pay and allowances

1. E-5½ - 11.005K (Average of E-5 and E-6 Pays)
2. O-3 - 20.409K

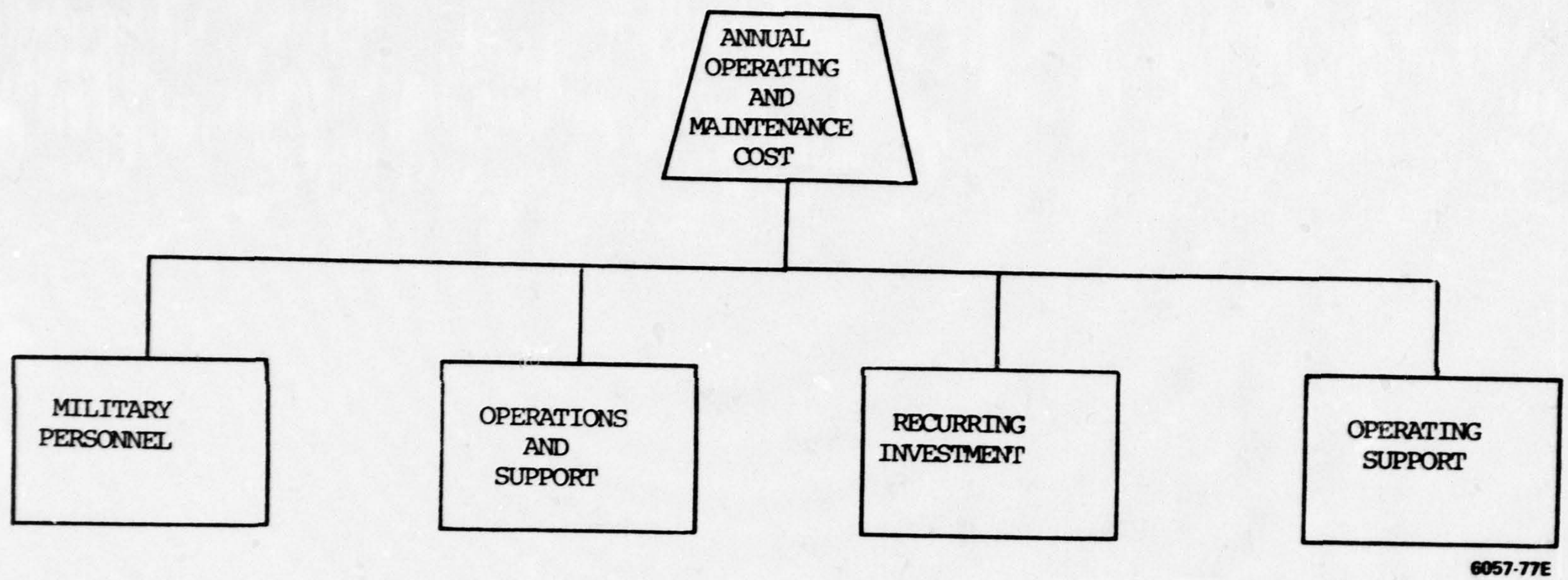

Figure 4-5. Annual Operating and Maintenance Costs Building Block Concept

b. Operating and Maintenance Support

1. Civilian Personnel: Pay Allowances - GS-9: 16.081K

2. Civilian Permanent Change of Station: Estimated changes X 1.740K

3. Transporation: Spares, supplies and STE CONUS Europe (14 percent)

4. Supplies and Equipment: 3 percent (PME + STE)

c. Recurring Investment - replacement spares (7 percent X PME+STE)

d. Operating Support

1. Base Operations: (total personnel X $625)

2. Depot Maintenance: operating and maintenance of the equipment - 0.5 percent X (PME+STE)

3. Replacement Training: tech control DCA composite (personnel X 3.16K)

4. Hospitals: $540 X personnel

5. Permanent Change of Station (Military): 1.985K X personnel

6. Power (DNC and CRF alternatives only)

4.3.2 Life Cycle Cost Calculations

The life cycle cost model described in the previous section was applied separately to each of the cost elements shown in Table 4-1 to allow simplified construction of the total life cycle cost for the six alternatives, two ATEC options, and two manpower reduction cases considered. As discussed previously, the operational factors obtained in sections 4.2.1 through 4.2.3 are incorporated into the life cycle cost for the baseline transmission element as personnel or equipment adjustments.

An example is provided to illustrate the method used to calculate the preliminary life cycle cost for each alternative. This result is preliminary in that it does not yet include an adjustment for circuit mileage savings. Table 4-15 demonstrates the method of calculation as applied to Alternative 2 (DNC-A only), Option a

TABLE 4-15. EXAMPLE OF LCC CALCULATION

- DNC-A WITHOUT ATEC, CASE I ($000)

YEAR	R&D CATEGORY	ESCALATION	ACQ CATEGORY	ESCALATION	O&M CATEGORY	ESCALATION	DISCOUNT	TOTAL
77							0.954	
78	101.76	1.077					0.867	
79	244.23	1.136					0.788	
80	143.21	1.205					0.717	1,013.6
81	497.5	1.271					0.651	
82	207.29	1.341					0.592	
83			100,902.587	1.402			0.538	76,108.8
84					25,531.484	1.505	0.489	
85						1.589	0.445	
86						1.678	0.405	
87						1.772	0.368	
88					⋮	1.871	0.334	157,414.4
89						1.976	0.304	
90						2.087	0.276	
91						2.204	0.251	
92					25,531.484	2.327	0.228	
93						2.454	0.208	

TOTAL = 234,536.8

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(without ATEC), Case 1 (maximum manpower reduction). As shown, R&D costs are distributed over a five-year period, 1978-1982; acquisition (procurement and installation) over one year (1983); and O&M over a 10-year life cycle (1984-1993). R&D costs are included only for DNC and CRF hardware. For the purposes of the study, ATEC and DCS baseline equipment is assumed to have been previously developed. Derivation of R&D costs is discussed in Appendix C.

As requested by DCEC, escalation and discounting factors are applied in accordance with reference 10. It should be noted that different escalation factors are applied to each of the three life cycle cost categories. Referring to Table 4-15, the total cost for any year is obtained by multiplying the appropriate cost category by its associated escalation factor and discount factor. The total life cycle cost is given by the sum of the yearly totals.

Table 4-16 is a summary of results obtained for all alternatives. The costs include escalation and discounting but not an adjustment for circuit mileage saving. The next section provides this adjustment and examines the results in detail.

TABLE 4-16. PRELIMINARY LIFE CYCLE COST RESULTS (1) ($000)

ALTERNATIVE (2)		R & D	ACQ	O & M (3)		LCC (3)	
				CASE 1	CASE 2	CASE 1	CASE 2
BASELINE	a	-	64,370.7	161,980.7	161,980.7	226,351.4	226,351.4
	b	-	77,709.3	159,890.3	163,306.4	237,599.6	241,015.7
DNC-A	a	1,013.6	76,108.8	157,414.4	166,595.3	234,536.8	243,717.7
	b	1,013.6	88,855.1	156,372.2	164,805.8	246,240.9	254,674.5
DNC-B	a	1,008.5	64,154.1	161,176.0	161,176.0	226,338.6	226,338.6
	b	1,008.5	77,420.2	158,514.1	162,366.2	236,942.8	240,794.9
DNC-A & DNC-B	a	1,697.8	76,550.2	156,656.7	165,837.9	234,904.7	244,085.9
	b	1,697.8	89,296.5	155,614.3	164,048.2	246,608.6	255,042.5
CRF	a	1,008.5	65,138.5	161,842.3	161,842.3	227,989.3	227,989.3
	b	1,008.5	78,404.7	159,830.0	163,246.1	239,243.2	242,659.3
DNC-A & CRF	a	2,022.1	76,846.8	156,943.9	166,124.9	235,812.8	244,993.8
	b	2,022.1	89,597.3	155,901.7	164,335.4	247,521.1	255,954.8

NOTES: (1) EXCLUDES IMPACT OF CIRCUIT MILE SAVINGS
(2) a - WITHOUT ATEC, b - WITH ATEC
(3) CASE 1 - MAXIMUM MANPOWER REDUCTION; CASE 2 - MINIMUM MANPOWER REDUCTION

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SECTION 5

COST BENEFITS STUDY RESULTS

5.1 COST BENEFITS ANALYSIS SUMMARY

In the previous sections, the cost and performance benefits of digital network control in the form of remotely controllable channel reassignment hardware were investigated. Procedures were developed for quantifying DNC operational benefits and for translating these benefits into cost factors which could be directly applied to life cycle cost analyses. The general areas of operational benefits examined include transmission capacity utilization, network reconfiguration, network flexibility, and AUTOSEVOCOM II interfacing. Reference 1, Section 3 analyzes DNC requirements and capabilities in each of these areas.

Five alternatives to the DCS baseline system were considered with respect to the above operational benefits. Not all alternatives provided all areas of operational benefits, and for this reason it is convenient to group the alternatives into three categories. The first category is represented by DNC-A (Alternative 2) and realizes all but the AUTOSEVOCOM II interfacing benefits. The second category is represented by DNC-B and the CRF (Alternatives 3 and 5, respectively) and realizes greater efficiency with respect to transmission capacity utilization and AUTOSEVOCOM II interfacing. The last category considers the joint deployment of DNC-A and DNC-B and the joint deployment of DNC-A and the CRF (Alternatives 4 and 6, respectively), and provides all areas of operational benefits.

Within this section, the life cycle cost analyses of section 4 are updated to include circuit mileage cost benefits and the results used to compare the effectiveness of the alternatives relative to each other and the baseline. Also, the sensitivity of the life cycle cost model to variations in personnel and equipment is determined. This is a valuable tool used in the effectiveness analysis, and which can be employed to investigate alternative DNC concepts, such as integrating the first level multiplexer with DNC-A (see section 5.2.3).

5.2 LIFE CYCLE COST SENSITIVITIES AND RESULTS

Life cycle cost is generally divided into three categories representing the three phases of equipment life - R&D, Acquisition and O&M. However, the costs associated with a system are derived from two principal sources: the equipment being procured and deployed, and the DCS personnel used to support this equipment. Based on the life cycle cost analyses in section 4, sensitivity factors are determined for changes in the following:

a. Equipment unit prices

b. Equipment deployment levels

c. Manpower levels.

Caution must be observed when applying the sensitivity factors for two reasons. First, all modifications to the baseline or DNC alternatives must be fully evaluated with respect to the impact on both cost sources. In general, any DNC hardware change to an alternative will also result in personnel changes due to the interrelationship between equipment levels and deployment, reliability/maintainability, and operational benefits as discussed in section 4. Thus, all modifications must be evaluated for both direct and indirect changes to equipment and personnel in order to properly estimate the total impact on life cycle cost. The second caution to be observed is that the sensitivity approach is only an estimation of the impact of a small system modification. However, verification by the model of several sensitivity estimated life cycle cost changes indicated close agreement between the two, with errors less than one-half of a percent.

The specific sensitivities determined for the life cycle cost model are as follows:

a. The addition or deletion of a single technical controller or maintenance person results in a respective increase or decrease of $106.8K in the life cycle cost O&M category. This assumes all baseline and DNC equipment levels remain constant and an E-5½ pay scale.

b. The addition or deletion of equipment increases or decreases, respectively, the life cycle cost acquisition category by factor of 2.1 times the uninstalled equipment cost associated with the change. This assumes that personnel levels remain constant.

c. The addition or deletion of equipment increases or decreases, respectively, the life cycle cost O&M category by a factor of 0.84 times the uninstalled equipment cost associated with the change.

It should be noted that these sensitivities are with respect to the 10-year life cycle considered and include the effects of escalation and discounting.

At this point, the impact of AUTOSEVOCOM II circuit mileage savings will be incorporated into the preliminary life cycle cost results given in Table 4-16. As described in section 4.2.4, circuit mileage savings appear as direct multiplexer reductions. In each of the DNC-B and CRF alternatives, the savings in first level multiplexer has already been considered; thus, only the additional savings due to second level multiplexers and KGs (because they are deployed on a one-to-one basis with second level multiplexers) will be examined. Assuming that the fill in each T1 is 21 out of 24 channels (this figure was estimated by DCEC), the total channel miles in the baseline network is 515773. Thus, the AUTOSEVOCOM II channel miles shown in Table 4-14 represent the following percentages of total network channel miles:

a. DNC-B - 1.35 percent

b. DNC-A/DNC-B - 2 percent

c. CRF - 0.57 percent

d. DNC-A/CRF - 0.57 percent.

Based on Table 2-1 and Appendix A, the second level multiplexer and KG represent $10311.6K or approximately 13 percent of the total uninstalled equipment cost for the baseline system. Applying the channel mileage savings percentages to this value and then applying

the approximate sensitivities factors, the resulting savings in Acquisition and O&M yield the total life cycle costs shown in Table 5-1. Implicitly assumed in this calculation is that the small savings in second level multiplexers and KGs which result do not cause any reduction in manning levels, which seems more than likely.

5.3 COST BENEFITS CONCLUSIONS

Table 5-1 summarizes the results of the cost benefits analysis and provides a basis for determining the cost effectiveness of the alternatives. For convenience, Figures 5-1 and 5-2 present the results of Table 5-1 in the form of differential life cycle costs relative to the DCS baseline system. Figure 5-1 compares the alternatives for Case 1, which considers the maximum manpower reduction likely through automation, and Figure 5-2 compares the alternatives for Case 2, which serves to lower bound the impact of automation.

As shown by these figures, the only alternative which is less costly than the DCS baseline system is DNC-B. This result holds true regardless of whether ATEC is deployed and regardless of the manpower reduction case considered. It is interesting to note that the relative ranking of the alternatives does not change between Cases 1 and 2 or between ATEC options within a case. The ranking of the alternatives with respect to total life cycle cost is always as follows.

a. DNC-B - Lowest Life Cycle Cost
b. Baseline
c. CRF
d. DNC-A and DNC-B
e. DNC-A
f. DNC-A & CRF - Highest Life Cycle Cost.

These results indicate that the relative cost effectiveness of the alternatives remains constant independent of ATEC and over the expected range of personnel reductions to be derived through atuomation. It is practical to compare the alternatives according to the three operational categories discussed in section 5.1. With respect to AUTOSEVOCOM II interfacing, DNC-B is clearly superior to either the presently planned manual AUTOSEVOCOM II interface used in the baseline system,

TABLE 5-1. LIFE CYCLE COSTS/COST BENEFITS RESULTS

		CASE 1	CASE 2
Baseline	a	226,351.4	226,351.4
	b	237,599.6	241,015.7
DNC-A	a	234,536.8	243,717.7
	b	246,240.9	254,674.5
DNC-B	a	225,929.4	225,929.4
	b	236,533.6	240,385.7
DNC-A & DNC-B	a	234,298.4	243,479.6
	b	246,002.3	254,436.2
CRF	a	227,816.5	227,816.5
	b	239,070.4	242,486.5
DNC-A & CRF	a	235,640.0	244,821.0
	b	247,348.3	255,782.0

a: Without ATEC
b: With ATEC
Case 1: Maximum Manpower Reduction
Case 2: Minimum Manpower Reduction

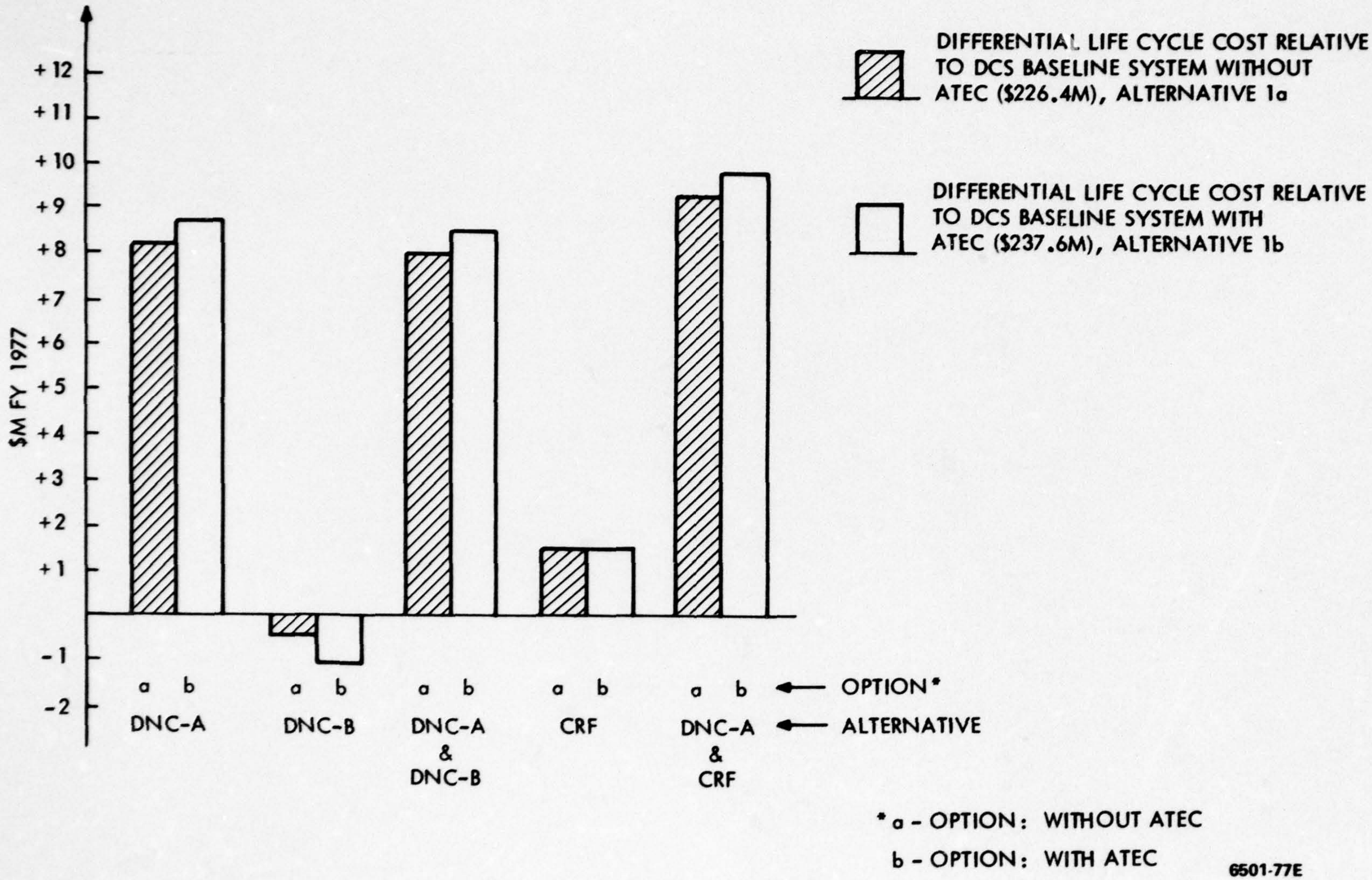

Figure 5-1. 10-Year Differential Life Cycle Costs, Case 1

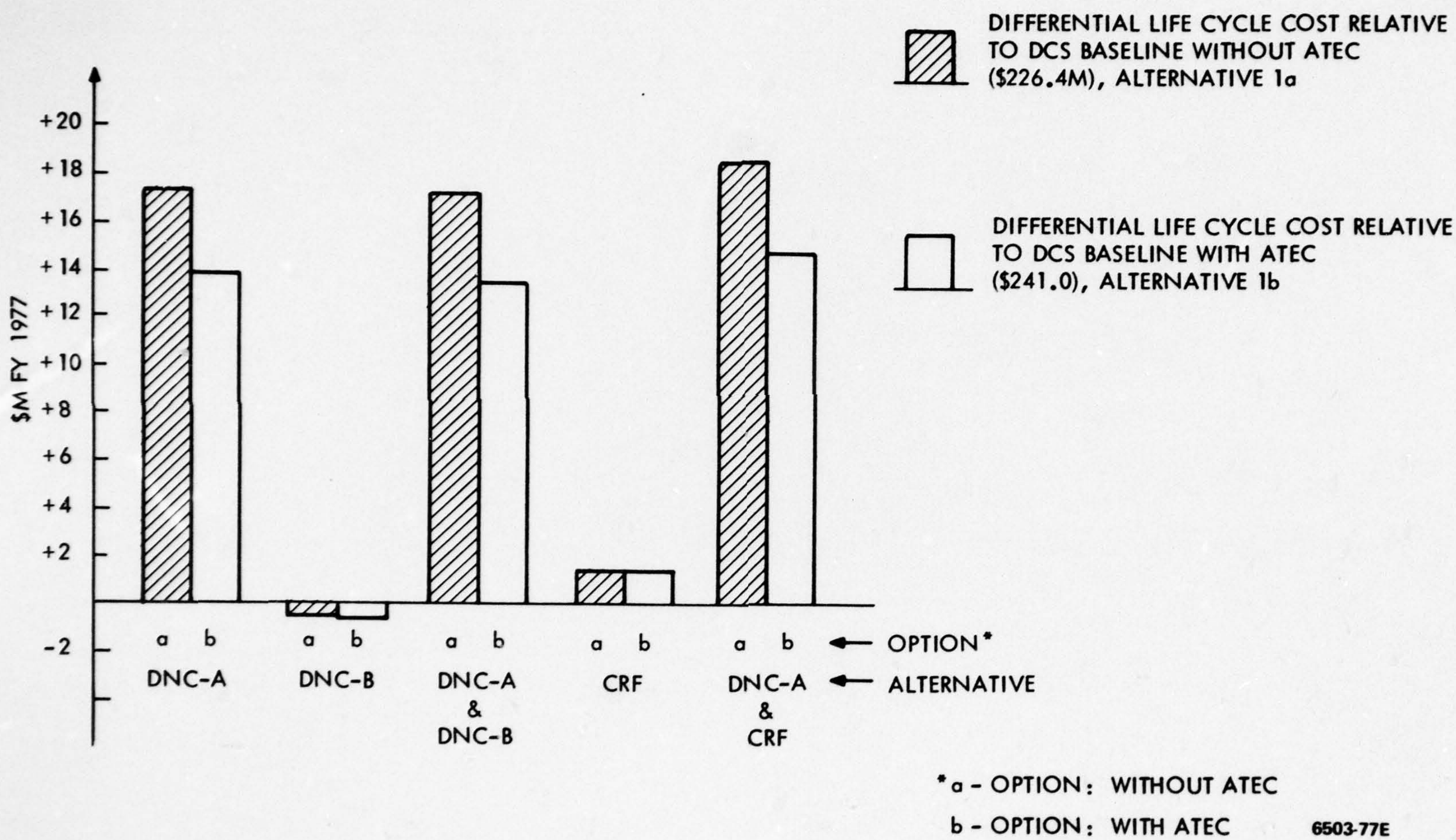

Figure 5-2. 10-Year Differential Life Cycle Costs, Case 2

Alternative 1, or the automated CRF interface, Alternative 2. The primary cost advantages of DNC-B over the CRF and manual interface derive from its more efficient equipment interface and its more efficient utilization of transmission capacity. With respect to performance, DNC-B provides as much rerouting flexibility and speed as the manual interface and considerably more than the CRF, due to the ability of DNC-B to reassign channels from one group to any other group to which it is connected.

Due to the cost effectiveness of the DNC-B, it follows immediately that there is nothing to be gained by deploying DNC-A without DNC-B since the latter provides functions which complement DNC-A. This is verified by Figures 5-1 and 5-2 which show that for a given ATEC option and manpower reduction case, the life cycle cost of DNC-A is for all practical purposes the same with or without DNC-B. Although the joint deployment of DNC-A and the CRF (Alternative 6) provides a similar effect, the performance advantages and related cost benefits of the DNC-A deployed with the DNC-B, as discussed in sections 3 and 4, make it the more cost-effective pairing, as is also verified by Figures 5-1 and 5-2.

Up to this point it was determined that DNC-B is the most effective AUTOSEVOCOM II and DNC-A interface. However, the decision to also deploy DNC-A in the baseline system depends on two considerations: the price to be paid for the added performance DNC-A provides in the transmission network, and the cost benefits which DNC-A realizes and could not be costed in this analysis.

Prior to discussing DNC-A deployment, it is necessary to ascertain the cost impact of ATEC on DNC-A. Referring to Figures 5-1 and 5-2, the additional cost above the baseline of DNC-A jointly deployed with DNC-B is for Case 1 - \$7.9M without ATEC and \$8.4M with ATEC, and for Case 2 - \$17.1M without ATEC and \$13.4M with ATEC. Thus, for Case 1, ATEC results in a slightly increased cost, while for Case 2 it significantly reduces cost. The reasons for these variations are as follows. In Case 1 (maximum manpower reduction), the combined impact of ATEC and DNC-A is, in effect, to saturate the technical controller

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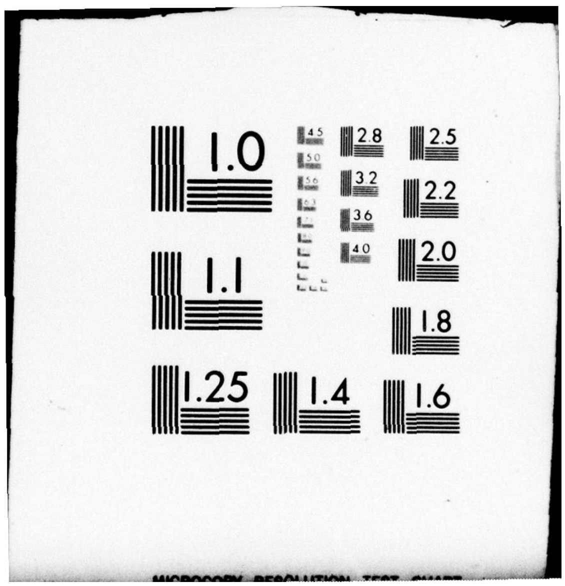
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model, thereby limiting manpower reduction benefits. Physically, this says that automation reaches a point of diminishing returns where additional automation does not further reduce manpower. Thus, in Case 1, when ATEC is added to DNC-A, it does not achieve sufficient cost benefits to offset its added Acquisition and O&M costs. In Case 2, the combined impact of ATEC and DNC-A is, in fact, totally additive resulting in considerable cost reductions. It may be concluded, therefore, that DNC-A and ATEC provide complementary functional capabilities and are desirable as a joint deployment. Additionally, since it may be assumed that the actual manpower reductions due to atuomation would be in the midrange between Cases 1 and 2 (or perhaps closer to Case 2), considerable cost savings arise from their joint deployment.

For DNC-A and DNC-B to be fully cost effective, the worth of the increased performance must be on the order of $7.9M to $17.1M (as determined from Figures 5-1 and 5-2), with the most likely value in the range of $10.9M which is the midpoint for Cases 1 and 2 with ATEC. To put the $10.9M in perspective, it may be seen that this represents less than 4.6 percent of the total baseline life cycle cost, and that the increased cost over the baseline attributable to ATEC (excluding DNC) as determined from Figures 5-1 and 5-2 is between $11.2M and $14.7M. Referring to Table 4-5, the performance benefits of ATEC and DNC-A are specified there in terms of reduction in service times for technical controller operations. Although ATEC provides a broader spectrum of benefits, the potential of DNC-A to reduce circuit outage restoration times is far greater. This reduction translates directly into improved network grade-of-service since circuit unavailability is improved accordingly. As estimated in section 4.2.1.1.3, DNC-A can reduce average circuit unavailability by as much as 78 percent.

The other consideration influencing the decision to deploy DNC-A is the expected impact of the operational benefits realized by DNC-A which could not be costed due to the unavailability of source data. For example the network flexibility of DNC-A makes it feasible to eliminate the need for dual routing of Priority 1 circuits, since DNC could provide reroutes by preemption or over spares almost immediately. Similarly, backhauling (or circuitous routing) which DNC can

minimize and in many cases eliminate was not considered. It should be noted that of the cost benefits which were considered, they defrayed between 26 (Case 2) to 66 (Case 1) percent of the life cycle costs associated with deploying DNC-A and DNC-B in the baseline system. To illustrate the significance of those benefits which could not be costed consider the following: if it is assumed that DNC eliminates backhauling, then only 17.7 percent backhauling in the baseline network would make DNC completely cost effective, regardless of other benefits.

5.4 DNC OPTIMIZATION CONCLUSIONS

A major objective of the cost benefits study was to reevaluate the recommended design and application of DNC as determined during the first eight tasks of the program. To this end, tradeoffs have been employed throughout the study to optimize the deployment of DNC hardware and to ensure maximum utilization of both DNC and DCS resources. As a result of this optimization process, DNC-B hardware was redesigned, application rules were modified in certain areas, and a modification to the first level multiplexer was recommended. These areas and the feasibility of integrating the first level multiplexer and TD-1192 are discussed below.

a. Based on previous results, the recommended interface of DNC-B with the transmission network was in all cases either the DNC-A or the 1.544-Mb/s side of the first and second level multiplexers. During the DNC-B deployment analysis, sections 3.2.3 and 3.2.4, it was determined that cost savings could be realized by interfacing the DNC-B with the equipment side of the first level multiplexer in certain cases. This was found advantageous at stations where a large number of inputs to the DNC-B were required and only on transmission cross sections with a few number of AUTOSEVOCOM II requirements. The advantage gained is that this interface permits higher utilization of the DNC-B switching matrix and precludes the need to expand the matrix to accommodate unused time slots.

b. It was previously recommended that DNC-B be deployed at all stations with AUTOSEVOCOM II requirements. This includes AN/TTC-39 and digital concentrator locations. Within the present study it was determined that in most cases, DNC-B hardware should not be used to interface digital concentrations at stations with no AN/TTC-39. The small number of trunks involved makes the manual interface more cost effective. It was verified, however, that DNC-B is the preferred interface to the AN/TTC-39 and digital concentrators at AN/TTC-39 locations.

The situation in which a DNC-B may be used to interface a digital concentrator-only site occurs during the joint deployment of DNC-A and DNC-B. In this case, it is sometimes desirable at locations equipped with a small DNC-A to replace the DNC-A by a DNC-B. The determination of whether a replacement is required involves a tradeoff between the additional hardware costs and the resulting circuit mileage savings. This tradeoff will be a function of the particular AUTOSEVOCOM II routing employed.

As discussed in section 3.2.4, it was determined that redesigning the DNC-B to permit substitution of DNC-Bs for DNC-As at large stations was not warranted due to the limited requirements involved.

c. Based on the results of the manning analysis, it is apparent that deployment of DNC-As to achieve a capability less than full flexibility is not desirable. This conclusion follows from the fact that the principal cost benefit of DNC-A derives from its network reconfiguration capability, which is severely limited in the partial interconnect, full interconnect and partial flexibility deployment schemes. This verifies the results obtained during Task 8 of the program.

d. The necessity to interface a large number of individual AUTOSEVOCOM II trunks and loops required that DNC-B hardware be redesigned to accept individual 16/32-kb/s channels and 2/4-kb/s subchannels. Previously, the DNC-B accepted only T1 and TRI-TAC formatted trunk groups. The attendant hardware change involved reducing the maximum trunk group capacity of the DNC-B and replacing this capacity by a multiplexing capability for channels and subchannels. The loss of these trunk group inputs does not affect DNC-B effectiveness. The associated software changes involve controlling the multiplexer and scanning for hardware fault indications. A similar channel dropping capability for DNC-A was not found to be warranted.

e. Using the developed sensitivity factors, it becomes feasible to estimate the cost effectiveness of integrating the DNC-A and first level multiplexer. Based on the design of VICOM first level multiplex (T1-4000), integration of it with DNC-hardware provides for a potential reduction of 1 out of 29 hardware modules. (It is assumed that the DRAMA first level multiplexer will have a similar design.) If it is optimistically assumed that additional economies can be achieved with respect to timing generation circuitry amounting to 5 percent, the total reduction in uninstalled equipment cost is on the order of 8.5 percent. Using the baseline deployment of first level multiplexers and the sensitivity factors, this reduction equates to a total life cycle cost reduction of $1184.4K or approximately 0.5 percent of the total life cycle cost for DNA-A Alternative 2a, Case 1. Thus, taking into consideration the following:

1. The integration does not provide significant, if any, space or power reductions

2. The integration does not preclude the requirement for numerous TD-1192 deployments without DNC-A

3. The integration does not provide significant cost benefits even excluding the additional R&D required.

It does not appear that the pairing of first level multiplexer and DNC is desired or justifiable.

f. As discussed in section 3.2.7, it was determined that potential cost savings can be achieved in all alternatives through the development of a 4-port multiplexer card for the first level multiplexer. This card would accept up to four 16-kb/s channels, would provide additional transmission efficiency since it requires no direct overhead channel, and could eliminate the need for a level A submultiplexer in AUTOSEVOCOM II. The estimated cost benefits include circuit mileage savings at least as great as in the joint deployment of DNC-A and DNC-B, and equipment reductions.

Using the sensitivity factors, the estimated cost impact is a reduction of at least $2278K which equals approximately 1 percent of the baseline life cycle cost. It therefore appears to warrant further consideration.

APPENDIX A

UNINSTALLED EQUIPMENT COSTS

Uninstalled equipment costs used in the life cycle cost analysis are either DCEC or GTE Sylvania-furnished. Costs provided by GTE Sylvania for commercially available equipment are based on average current vendor prices.

Table A-1 specifies the costs for all equipments. ATEC costs shown assume the sector, node and station requirements and deployment given in sections 2 and 3. Figure A-1 is a cost summary for the IRGB/CEG, including the modifications specified in section 3.2.3. Figure A-1 supersedes Figure 9-2 of Reference 1.

TABLE A-1. UNINSTALLED EQUIPMENT COSTS

GFI ($000)		GTE SYLVANIA-FURNISHED ($000)	
KG-81	23.0	DNC-A (CEG)	77.4-190.0
TD-1192	16.8	DNC-B (CEG)	103.2-138.1
TD-1193		LM	1.8
4 Port	16.4	GM	1.8
8 Port	21.6	LGM	
FRC-163	38.0	8 Channel	8.5
SMA		16 Channel	13.5
4 Channels	3.5	TGM	13.5
8 Channels	4.0	DNC Control	
16 Channels	5.0	Station CPU	2.0
SYSCON Interface	2.0	Nodal CPU	4.0
Patch Appearances	.085	VDU/KB	1.0
CRF	150.0	Mass Storage	2.0
ATEC	6270	Printer	5.0
		MUX -16 Channel	2.0

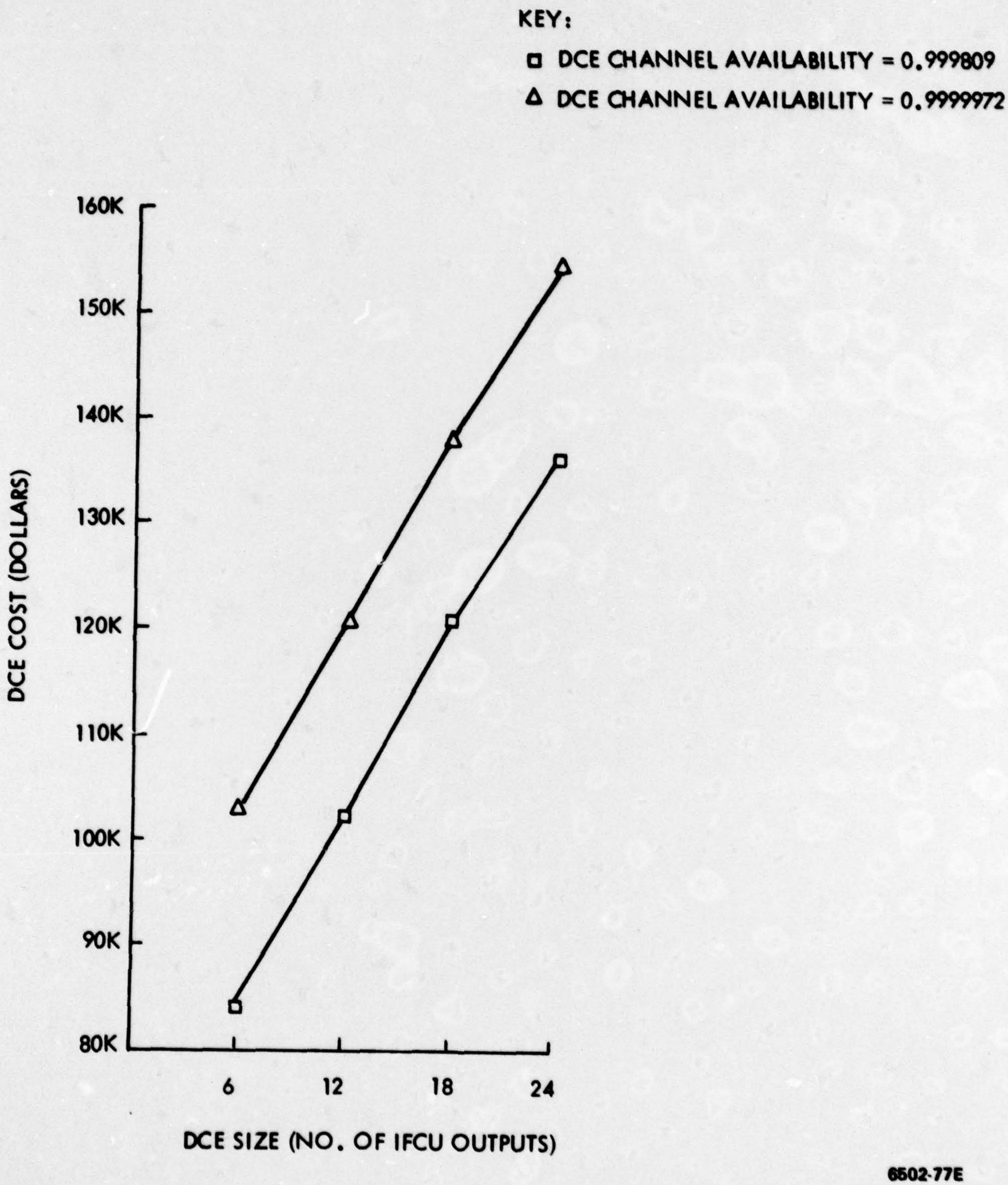

Figure A-1. DCE Cost Summary for IRGB and DCE Configuration

APPENDIX B

MANNING ANALYSIS-QUEUEING FORMULATION*

The service rates and arrival rates for the three types of random technical control operations are denoted as follows:

Operation	Service Rate	Arrival Rate
1. Circuit Outages	μ_1	λ_1
2. Assistance to Other Facilities	μ_2	λ_2
3. Near-Real-Time Reports	μ_3	λ_3

The aggregate arrival rate is given by

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3$$

and the weighted average service rate is given by

$$\mu = \frac{\lambda}{\lambda_1/\mu_1 + \lambda_2/\mu_2 + \lambda_3/\mu_3}.$$

If the model contains k servers, then the expected number of arrivals of all types in queue $\bar{q}$, is given by

$$\bar{q} = B(\rho/(1-\rho)) + k\rho$$

where

$$\rho = \lambda/\mu k,$$

$$B = (1-(a/b))/(1-(\rho a/b)),$$

$$a = \sum_{n=0}^{k-1} (k\rho)^n/n! \text{ , and}$$

---

*Refer to Reference 11 for detailed discussion of the application of the M/M/k queueing model to technical control facility.

$$b = \sum_{n=0}^{k-1} (k\rho)^n/n! .$$

The expected number of inoperative circuits $E(N_c)$ in queue is

$$E(N_c) = \lambda_1\bar{q}/\lambda ;$$

whereupon, for a station with T_c total circuits, the expected technical control facility availability $E(N)$ (analysis figure of merit as described in section 4.2.1.1.1) is

$$E(N) = (T_c - E(N_c))/T_c .$$

Also of interest is the fractional standby time per technical controller. This is given by the expression $(1 - \lambda/k\mu)$.

APPENDIX C

DIGITAL NETWORK CONTROL R&D COSTS

DNC R&D costs are based on a program to implement, develop and test Digital Network Control (DNC) feasibility models. The DNC feasibility models developed under this program would be configured through hardware and control software to provide the capability to completely evaluate the impact of automatic DNC on DCS operations and control capabilities with respect to the DCS transmission subsystem. The models would also be configured to permit the evaluation of DNC in providing interoperability with TRI-TAC and AUTOSEVOCOM II.

The program should, as a minimum, consist of the design, development, fabrication, and test of three feasibility models of an automatic DNC. The automatic DNC would be designed and configured to provide the interface and reassignment of DCS 64 kb/s PCM byte-oriented channels used in T1 digital groups, 16/32-kb/s bit-oriented channel used in TRI-TAC formatted digital groups, and 2/4-kb/s bit-oriented subchannels which make up the TRI-TAC overhead channels. In addition, the DNC would be remotely controlled and would provide control and coordination of the network to which it is assigned.

The automatic DNC would be configured to handle modular subsets of 64 T1s and 6 TRI-TAC formatted digital groups. Digital switching techniques would be utilized to accomplish the automated channel reassignment capability. The DNC hardware would be designed for modular construction in both size and function. The automatic DNC would be designed to:

a. Rapidly reconfigure network to meet user demands and stress conditions

b. Efficiently interface AUTOSEVOCOM II and TRI-TAC with the transmission backbone

c. Rapidly restore high priority and special interest circuits

d. Provide loopback capability

e. Provide a means for DCS transmission control to perform performance assessment and fault isolation

f. Provide the capability to automate the tech control functions at unattended stations.

It is projected that the design, development, fabrication and test of the DNC feasibility models would require a program schedule of approximately 22 months.

Following the DNC feasibility program, it would be recommended that a program be implemented to develop DNC prototype models. The prototype models should incorporate any design improvements resulting from the DNC feasibility program.

The prototype program should consist of the fabrication and testing in DEB of a minimum of three prototype models. The purpose of this program would be to demonstrate the capabilities of DNC in an operational environment.

The DNC prototype models should be remotely controlled to demonstrate the capabilities for digital network control defined during Tasks 1 through 8, and demonstrated during the DNC feasibility program. The DNC prototype program schedule would be approximately eighteen months in duration and is also included in the R&D cost.

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